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The effect of altered streamflow on existing municipal and agricultural users of the Yellowstone River Basin, Montana

YELLOWSTONE IMPACT STUDY

TECHNICAL REPORT NO. 9

REFERENCE COLLECTION

prepared for

THE
OLD WEST REGIONAL
COMMISSION

by

JULY 1977

WATER RESOURCES DIVISION
DEPARTMENT OF NATURAL RESOURCES & CONSERVATION

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The effect of altered streamflow on existing municipal and agricultural users of the Yellowstone River Basin, Montana

by

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conducted by the

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July 1977

The Old West Regional Commission is a Federal-State partnership designed to solve regional economic problems and stimulate orderly economic growth in the states of Montana, Nebraska, North Dakota, South Dakota and Wyoming. Established in 1972 under the Public Works and Economic Development Act of 1965, it is one of seven identical commissions throughout the country engaged in formulating and carrying out coordinated action plans for regional economic development.

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FOREWORD

The Old West Regional Commission wishes to express its appreciation for this report to the Montana Department of Natural Resources and Conservation, and more specifically to those Department staff members who participated directly in the project and in preparation of various reports, to Dr. Kenneth A. Blackburn of the Commission staff who coordinated the project, and to the subcontractors who also participated. The Yellowstone Impact Study was one of the first major projects funded by the Commission that was directed at investigating the potential environmental impacts relating to energy development. The Commission is pleased to have been a part of this important research.

George D. McCarthy
Federal Cochairman

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Abbreviations used in this report

af	acre-feet
bhp	brake horsepower
cfs	cubic feet per second
d	days
ft	feet
gal	gallons
gpm	gallons per minute
hm^3	cubic hectometers
hp	horsepower
km	kilometers
kwh	kilowatt-hour
l	liters
m	meters
m^2	square meters
m^3	cubic meters
m^3/s	cubic meters per second
m^3/y	cubic meters per year
mmaf/y	million acre-feet per year
mgd	million gallons per day
mo	months
mw	megawatts
USGS	United States Geological Survey

Preface

THE RIVER

The Yellowstone River Basin of southeastern Montana, northern Wyoming, and western North Dakota encompasses approximately 180,000 km^2 (71,000 square miles, 92,200 (35,600) of them in Montana. Montana's portion of the basin comprises 24 percent of the state's land; where the river crosses the border into North Dakota, it carries about 8.8 million acre-feet of water per year, 21 percent of the state's average annual outflow. The mainstem of the Yellowstone rises in northwestern Wyoming and flows generally northeast to its confluence with the Missouri River just east of the Montana-North Dakota border; the river flows through Montana for about 550 of its 680 miles. The major tributaries, the Boulder, Stillwater, Clarks Fork, Bighorn, Tongue, and Powder rivers, all flow in a northerly direction. The western part of the basin is part of the middle Rocky Mountains physiographic province; the eastern section is located in the northern Great Plains (Rocky Mountain Association of Geologists 1972).

THE CONFLICT

Historically, agriculture has been Montana's most important industry. In 1975, over 40 percent of the primary employment in Montana was provided by agriculture (Montana Department of Community Affairs 1976). In 1973, a good year for agriculture, the earnings of labor and proprietors involved in agricultural production in the fourteen counties that approximate the Yellowstone Basin were over $141 million, as opposed to $13 million for mining and $55 million for manufacturing. Cash receipts for Montana's agricultural products more than doubled from 1968 to 1973. Since that year, receipts have declined because of unfavorable market conditions; some improvement may be in sight, however. In 1970, over 75 percent of the Yellowstone Basin's land was in agricultural use (State Conservation Needs Committee 1970). Irrigated agriculture is the basin's largest water use, consuming annually about 1.5 million acre-feet (af) of water (Montana DNRC 1977).

There is another industry in the Yellowstone Basin which, though it consumes little water now, may require more in the future, and that is the coal development industry. In 1971, the North Central Power Study (North Central Power Study Coordinating Committee 1971) identified 42 potential power plant sites in the five-state (Montana, North and South Dakota, Wyoming, and Colorado) northern Great Plains region, 21 of them in Montana. These plants, all to be fired by northern Great Plains coal, would generate 200,000 megawatts (mw) of electricity, consume 3.4 million acre-feet per year (mmaf/y) of water, and result in a large population increase. Administrative, economic, legal, and technological considerations have kept most of these conversion facilities, identified in the North Central Power Study as necessary for 1980, on the drawing board or in the courtroom. There is now no chance of their being completed by that date or even soon after, which will delay and diminish the economic benefits some basin residents had expected as a result of coal development. On the other hand, contracts have been signed for the mining of large amounts of Montana coal, and applications have been approved not only for new and expanded coal mines but also for Colstrip Units 3 and 4, twin 700-mw, coal-fired, electric generating plants.

In 1975, over 22 million tons of coal were mined in the state, up from 14 million in 1974, 11 million in 1973, and 1 million in 1969. By 1980, even if no new contracts are entered, Montana's annual coal production will exceed 40 million tons. Coal reserves, estimated at over 50 billion economically strippable tons (Montana Energy Advisory Council 1976), pose no serious constraint to the levels of development projected by this study, which range from 186.7 to 462.8 million tons stripped in the basin annually by the year 2000. Strip mining itself involves little use of water. How important the energy industry becomes as a water user in the basin will depend on: 1) how much of the coal mined in Montana is exported, and by what means, and 2) by what process and to what end product the remainder is converted within the state. If conversion follows the patterns projected in this study, the energy industry will use from 48,350 to 326,740 af of water annually by the year 2000.

A third consumptive use of water, municipal use, is also bound to increase as the basin population increases in response to increased employment opportunities in agriculture and the energy industry.

Can the Yellowstone River satisfy all of these demands for her water? Perhaps in the mainstem. But the tributary basins, especially the Bighorn, Tongue, and Powder, have much smaller flows, and it is in those basins that much of the increased agricultural and industrial water demand is expected.

Some impacts could occur even in the mainstem. What would happen to water quality after massive depletions? How would a change in water quality affect existing and future agricultural,industrial, and municipal users? What would happen to fish, furbearers, and migratory waterfowl that are dependent on a certain level of instream flow? Would the river be as attractive a place for recreation after dewatering?

One of the first manifestations of Montana's growing concern for water in the Yellowstone Basin and elsewhere in the state was the passage of significant legislation. The Water Use Act of 1973, which, among other things, mandates the adjudication of all existing water rights and makes possible the reservation of water for future beneficial use, was followed by the Water Moratorium Act of 1974, which delayed action on major applications for Yellowstone Basin water for three years. The moratorium, by any standard a bold action, was prompted by a steadily increasing rush of applications and filings for water (mostly for industrial use) which, in two tributary basins to the Yellowstone, exceeded supply. The DNRC's intention during the moratorium was to study the basin's water and related land resources, as well as existing and future need for the basin's water, so that the state would be able to proceed wisely with the allocation of that water. The study which resulted in this series of reports was one of the fruits of that intention. Several other Yellowstone water studies were undertaken during the moratorium at the state and federal levels. Early in 1977, the 45th Montana Legislature extended the moratorium to allow more time to consider reservations of water for future use in the basin.

THE STUDY

The Yellowstone Impact Study, conducted by the Water Resources Division of the Montana Department of Natural Resources and Conservation and financed by the Old West Regional Commission, was designed to evaluate the potential physical, biological, and water use impacts of water withdrawals and water development on the middle and lower reaches of the Yellowstone River Basin in Montana. The study's plan of operation was to project three possible levels of future agricultural, industrial, and municipal development in the Yellowstone Basin and the streamflow depletions associated with that development. Impacts on river morphology and water quality were then assessed, and, finally, the impacts of altered streamflow, morphology, and water quality on such factors as migratory birds, furbearers, recreation, and existing water users were analyzed.

The study began in the fall of 1974. By its conclusion in December of 1976, the information generated by the study had already been used for a number of moratorium-related projects--the EIS on reservations of water in the Yellowstone Basin, for example (Montana DNRC 1976). The study resulted in a final report summarizing all aspects of the study and in eleven specialized technical reports:

Report No. 1	Future Development Projections and Hydrologic Modeling in the Yellowstone River Basin, Montana.
Report No. 2	The Effect of Altered Streamflow on the Hydrology and Geomorphology of the Yellowstone River Basin, Montana.
Report No. 3	The Effect of Altered Streamflow on the Water Quality of the Yellowstone River Basin, Montana.
Report No. 4	The Adequacy of Montana's Regulatory Framework for Water Quality Control
Report No. 5	Aquatic Invertebrates of the Yellowstone River Basin, Montana.
Report No. 6	The Effect of Altered Streamflow on Furbearing Mammals of the Yellowstone River Basin, Montana.
Report No. 7	The Effect of Altered Streamflow on Migratory Birds of the Yellowstone River Basin, Montana.

Report No. 8 The Effect of Altered Streamflow on Fish of the Yellowstone and Tongue Rivers, Montana.

Report No. 9 The Effect of Altered Streamflow on Existing Municipal and Agricultural Users of the Yellowstone River Basin, Montana.

Report No. 10 The Effect of Altered Streamflow on Water-Based Recreation in the Yellowstone River Basin, Montana.

Report No. 11 The Economics of Altered Streamflow in the Yellowstone River Basin, Montana.

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The authors thank everyone who contributed time and experience to this study, including Richard Cottingham and his surveying crew: instrument man Tom Ferguson and rodmen Steve White, Walt Siler, Pat Herron, and Randy Yeager.

Special thanks are due John Voelker, Superintendent of Public Utilities in Billings, and his staff: Mike Thomas, Assistant Superintendent; Carl Christenson, Business Manager; Duane Madsen, Chief Chemist, and Bill Fielder, Chemist. Thanks also go to Pat Rogers, Miles City Assistant City Engineer, and Bob Leidholt, Miles City Water Plant Operator, as well as Glendive Mayor Lyle Allen, and former Glendive Public Works Director Bob Knapp.

This report was reviewed and guided by John C. Orth and Ted J. Doney, former director and Director, respectively, of the Montana Department of Natural Resources and Conservation (DNRC); Orrin Ferris, Administrator of the DNRC's Water Resources Division; and Carole Massman, of the DNRC's Special Staff. Norman Barnard confirmed data and rewrote portions of the original draft.

Other department personnel providing assistance were Edward Miller, David Lambert, and Ronald Schleyer who performed editing tasks, and Patti McCarthy, typist. Graphics were coordinated and produced by Gary Wolf, with the assistance of Gordon Taylor, Dan Nelson, and June Virag. The cover was designed and executed by D. C. Howard.

Introduction

PURPOSE

The purpose of this study was to investigate some of the adverse effects that a decrease in the accessibility of water, as a result of reduced flows, would have on the existing municipal and agricultural water users in the Yellowstone River Basin of Montana.

SCOPE

The study focused on three municipalities that provide potable water for domestic and industrial uses and on numerous agricultural water diversions. Presumably, these existing users have valid water rights which will protect their water from the competition of future appropriators. But existing uses also could be adversely affected by a decrease in the accessibility of water. Future diversions extensive enough to decrease flows could lower the surface elevation of water in the river channel. Some diversion structures might thereupon require expensive modification. A lower water-surface elevation at pump intakes also could affect pumping efficiency, thus increasing the energy cost of pumping.

The potential changes in accessibility of water and costs of obtaining it are the subjects of this report.

STUDY AREA

The relationship between the amount of water pumped per kilowatt-hour (kwh) and accessibility of that water for municipal purposes was studied for Billings, Miles City, and Glendive. All three cities rely on water from the Yellowstone River for their municipal water systems.

Four pumping and twelve gravity-irrigation diversions within the Yellowstone basin also were examined to determine the effects of reduced streamflows.

Yellowstone River Basin

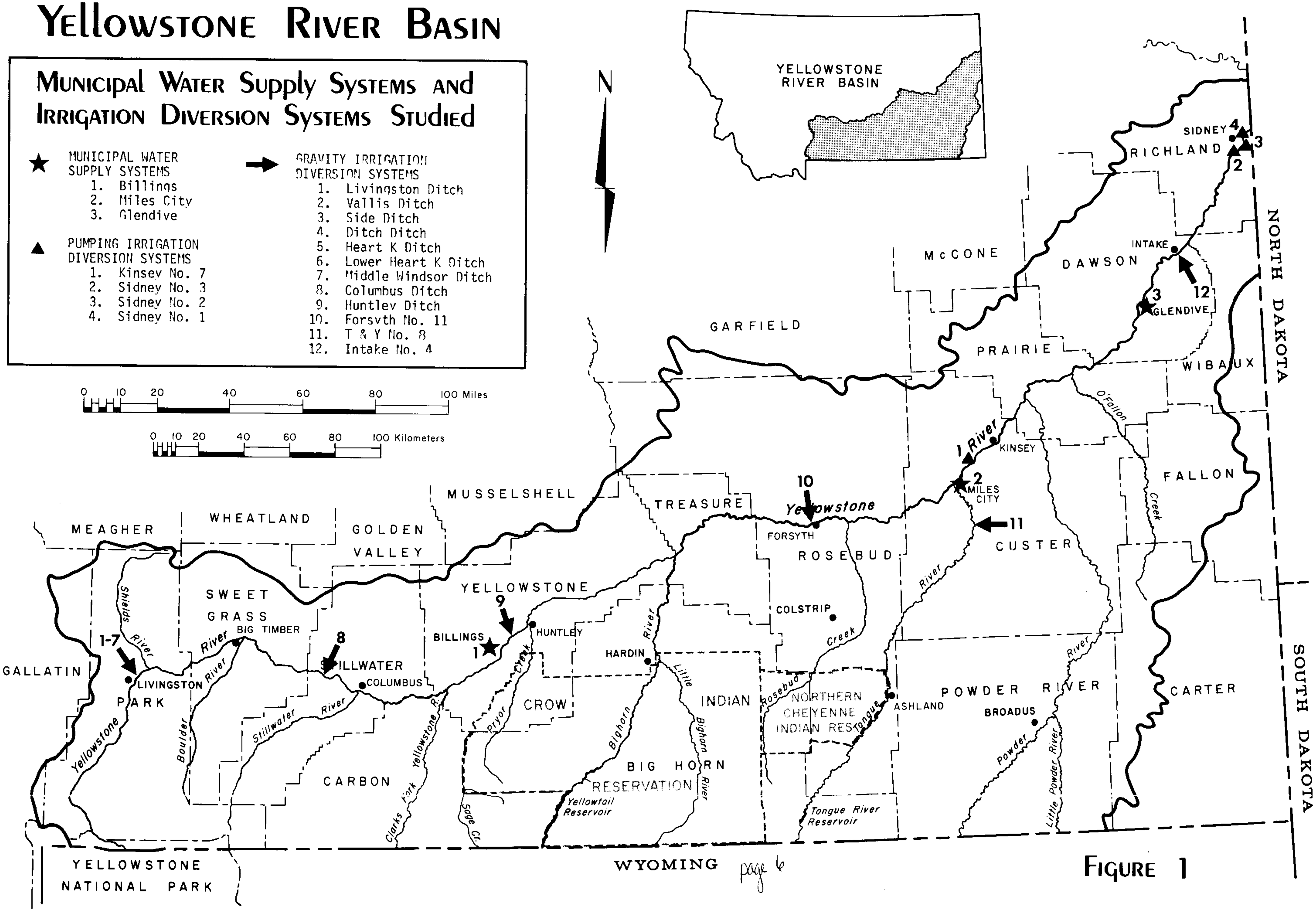

FIGURE 1

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Methods

MUNICIPAL WATER SYSTEMS

Billings, Miles City, and Glendive draw their municipal water supplies directly from the Yellowstone River (see figure 1). Before being pumped into the treatment plant proper, water pumped by low-service pumps under 10 to 30 ft (3 to 10 m) of head enters into pre-settlement basins.

Data collected at the three municipal sites consisted of the number of kilowatt-hours (kwh) of electricity used by the municipal plants, the total amounts of water pumped from the river, and cost of chemical water treatment. The data collected for recent years reflect present water-use rates, existing pump and motor efficiencies, present needs, and future trends. The periods of data collection were: Billings, 1971-75; Miles City, 1974; and Glendive, 1973-75.

Streamflow data were collected at each municipal pump site. Monthly streamflow data for the Yellowstone River at Billings were taken from the USGS stream-gaging station at Billings. Daily streamflows for the municipal water supply plant at Miles City were determined by subtracting streamflows recorded at the USGS station on the Tongue River at Miles City from the streamflow records for the USGS station on the Yellowstone River at Miles City. Monthly streamflows for the Yellowstone River at Glendive were determined by adding streamflow data from the USGS stream-gaging station on the Yellowstone River near Sidney to the flows diverted by the Lower Yellowstone Canal at Intake. (USDI 1971-74).

For each of the municipal systems, an attempt was made to correlate the river elevation and the number of gallons of water pumped per kwh of power consumed by the system. The attempt relied on monthly historical data on electrical consumption and average river stage during those months. The results appear in tables 1, 2, and 3.

Although they are based on accurate data and are consistent with the sensible notion that projected pumping costs would increase as the river level declined, the results presented in these tables are not conclusive of the effects of river-surface elevation on pumping costs. There are several reasons why the data fail to demonstrate the presumed effect.

First, the power consumption of the low-service pumps that handle the initial withdrawal at each of the plants is not metered separately and therefore forms an unknown part of the total plant electrical consumption which was measured. Total plant electrical consumption, in turn, varies not only with the volume of water pumped (an effect taken into account in the tables) but also with the turbidity of the intake water, the variation in pumping head from the level at which the pumps are most efficient, and other factors that vary month to month.

Second, a 2- or 3-foot (half to one meter) change in water-surface elevation of the river (affecting low-service funds only) is a minor factor in total plant electrical consumption when the water plant's high-service pumps may be working to lift water additional hundreds of feet. (Note the complete facilities of the Billings water-treatment plant illustrated in figure 2.)

Finally, the historical data used to demonstrate the correlation between average monthly river-surface elevation and pumping costs fail to take into account that, within an average month, actual river levels may vary widely and cause changes in pumping plant efficiency that would not appear if the elevation were constant.

For all of these reasons, despite the conclusions indicated in tables 1, 2, and 3, it is unknown whether decreased river flows would have a significant effect on pumping costs at water-treatment plants in Billings, Miles City, and Glendive.

For this study, the cost of the electricity was assumed to remain the same for each projected level of development.

IRRIGATION SYSTEMS

The four pumping and twelve gravity irrigation diversions shown in figure 1 were examined for the effect of lowered streamflow on each diversion. (Appendix B contains detailed maps of the diversions.)

Because they are in a part of the Yellowstone River drainage where lowered streamflows would occur, four irrigation pumping diversions were selected: Kinsey No. 7, Sidney No. 1, Sidney No. 2, and Sidney No. 3. (The numbers refer to the numbering system for irrigation diversions determined by the Yellowstone Impact Study team.) The three Sidney pumping plants are located on the Yellowstone River near Sidney; Kinsey No. 7 is near Kinsey. Information concerning the pumps, sump detail, water use, and power use for these sites was easily accessible.

Three of the gravity diversions selected for study (Forsyth No. 11, Tongue and Yellowstone No. 8, and Intake No. 4) have dams that extend the entire width of the river. They are the major gravity diversions in the Lower Yellowstone Basin. Forsyth No. 11 is a concrete and rock dam across the Yellowstone River at Forsyth. Tongue and Yellowstone (T & Y) No. 8 is a concrete diversion dam across the Tongue River south of Miles City, and Intake No. 4 is a concrete and rock diversion dam across the Yellowstone River at Intake.

Cross sections of the river were surveyed, and a computer program was used to calculate water-surface profile at each cross section. Six cross sections were surveyed for most of the diversions studied: four below, one at, and one above each diversion. The cross sections included the river channel and overbank; they were spaced approximately 750 ft (230 m) apart. The T & Y No. 8 diversion did not require cross-section surveys because it is a weir of known design. (The river-stage versus discharge curve could be developed from the characteristics of the weir.)

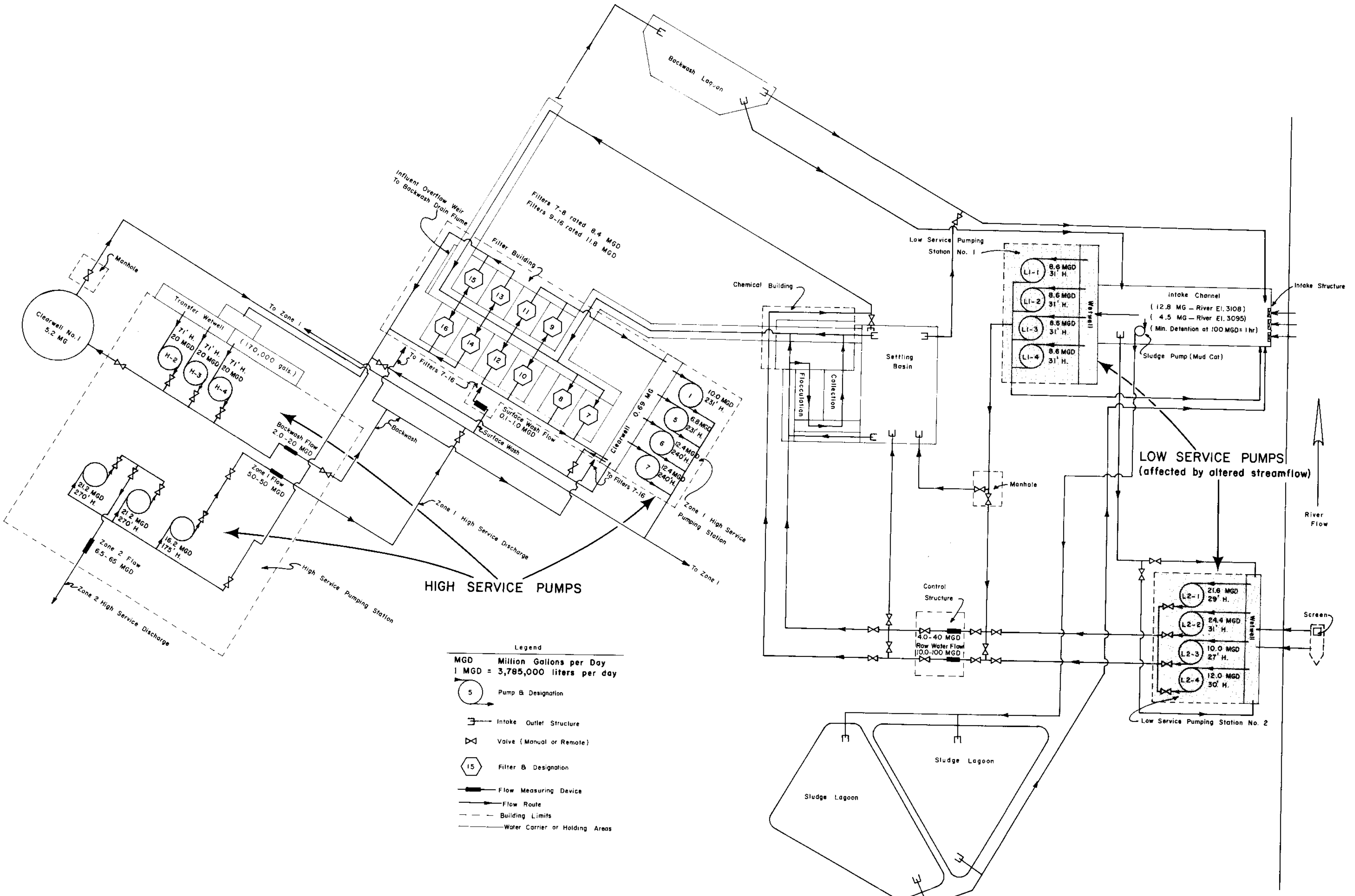

Figure 2. Schematic of Billings water treatment plant.

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While surveying the cross sections, the water-surface elevation at each cross section was recorded, and the flow in the river was calculated for each water-surface elevation. These water-surface profiles and discharge data were then used to calibrate the river stage versus discharge relationships computed in the water-surface profile computer program.

Maps locating the cross sections taken at each site are found in appendix B. (Complete cross section data and stage versus discharge information for each irrigation diversion, and all pertinent information concerning the pumping station, diversion dam, and headgates, for each site are on file with the Montana Department of Natural Resources and Conservation in Helena.

A cost analysis was made for each irrigation-pumping diversion. These analyses were successful because power costs for the pumps had been recorded. Modeling of the river using the State Water Planning Model with hypothetical levels of future development (appendix A) led to a regime of altered streamflows (see appendix C). A water-surface profile program (HY50) then was used to predict a new set of water-surface profiles for the various levels of development. Costs associated with these lowered water-surface profiles were calculated from the stage-discharge relationships for each pump site, assuming a cost of 2.5 mills/kwh. (The Montana Public Service Commission in July 1977 approved an increase to 10.0 mills/kwh for > 2500 kwh/hp connected.)

Nine other gravity-irrigation diversions (seven near Livingston, one near Columbus, and one near Huntley) were studied. All of the canals have minor headgate structures built at the head end (appendix B). It was assumed that the streamflow rating table for the USGS stream gaging station near Livingston applied to the river section at all seven Livingston diversions. Similarly, it was assumed that the rating table for the Yellowstone River at Billings applied to the diversions near Columbus and Huntley. Discharges and elevations of the bottoms of the headgates were measured at each of the diversions.

Existing situation and future impacts

MUNICIPAL SYSTEMS

Water-use data collected for Billings, Miles City, and Glendive were tabulated for calculation (appendix D). Attempts were made to derive gallons pumped per kilowatt-hour. The calculations were inappropriate in that the treatment-system pumping requirements were not related to the river stage, and in-system pumping costs were not separately identifiable.

BILLINGS

The Billings municipal water plant has two intakes for water from the Yellowstone River (figure 3). One intake is used during winter (November through April), and the other is used during June and July. During the remaining months (May and August through October) both intakes are used.

The Billings municipal water supply system has no problems getting water from the river except during winter ice jams (Thomas 1976). Immediately upstream from the pumping plant the river is divided by several islands. In ice conditions, ice in the west channel forces water to the east channel away from the pumping plant intakes. Occasionally, dynamite has been used to remove the ice jams in the west channel.

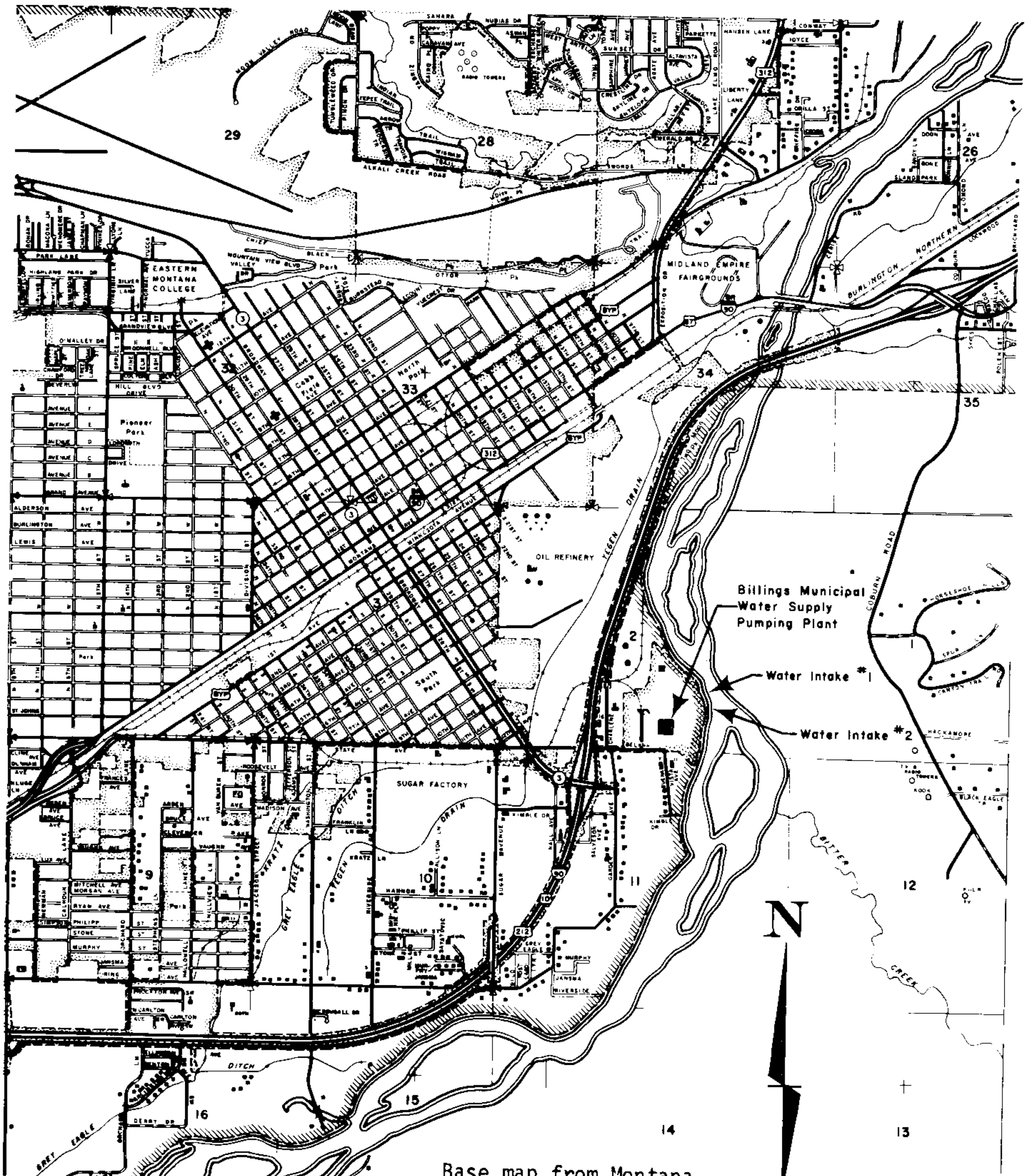
Table 1 shows the estimated average monthly electrical cost for the Billings municipal water supply system for the natural flow in the Yellowstone River. Also shown are calculated costs for projected levels of development (Billings 1976ab). Streamflow estimates for the various levels of development are in appendix D.

Based on the three levels of development, and the corresponding water-surface elevations, the operating costs of the low-service pumps for the natural flow and for three projected river-surface elevations are substantially the same.

MILES CITY

Table 2 shows an estimated average monthly cost for treating and pumping water from the Yellowstone River at the Miles City municipal water supply system (figure 4). Comparative costs are shown for the natural streamflow, and for low, intermediate, and high levels of development (Miles City 1974). Streamflow estimates at the three levels of development are presented in appendix D.

The cost data presented in table 2 show that electrical costs could increase from 4 to 8 percent over costs associated with the natural flow depending on the development level.



Base map from Montana
Department of Highways.

Figure 3. Billings municipal water supply system.

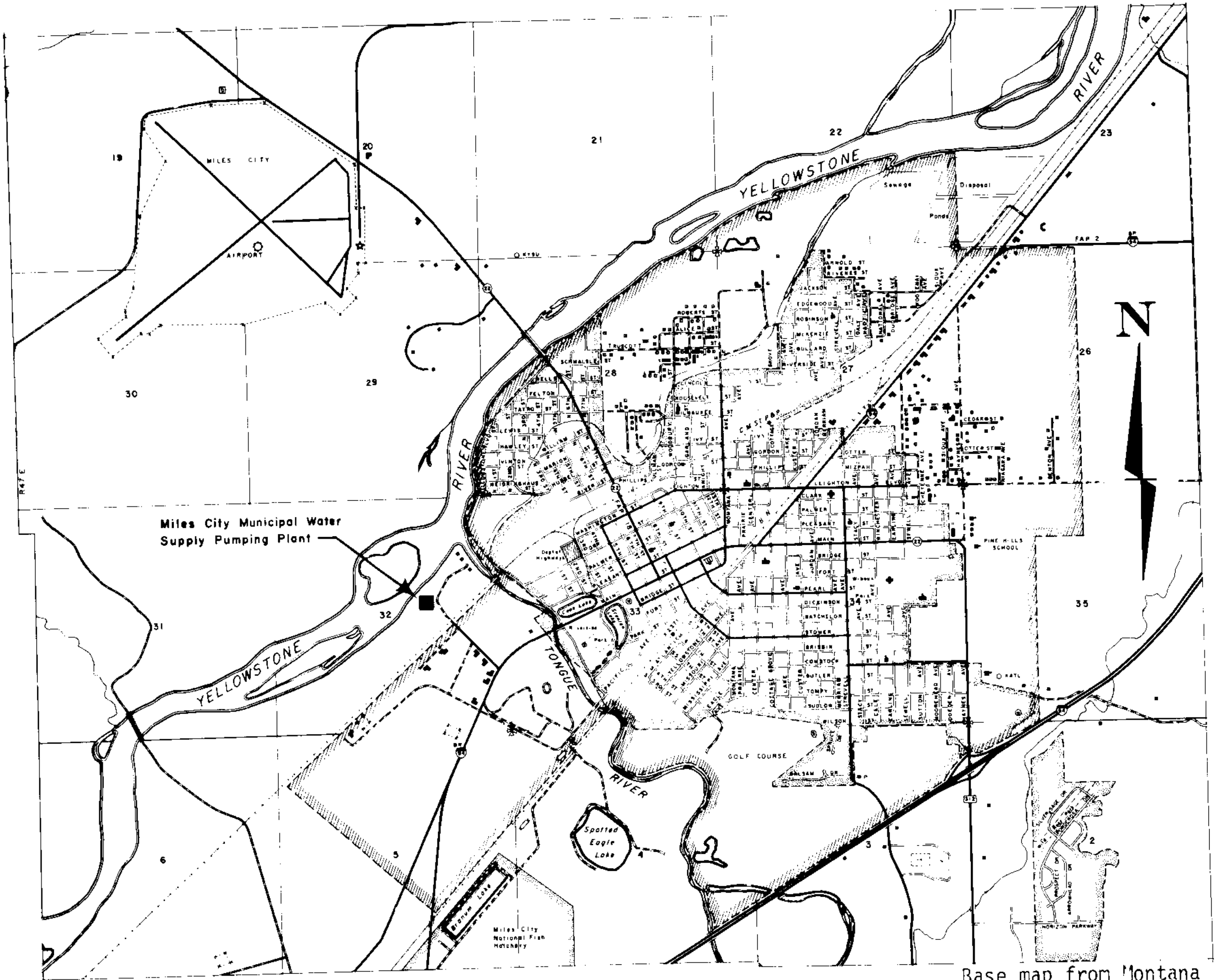


Figure 4. Miles City municipal water supply system.

Base map from Montana
Department of Highways.

TABLE 1. Electrical Cost of Billings municipal water supply system.

MONTH	WATER USED[a] (Million Gallons)	ELECTRICAL COST			
		Natural Flow	Levels of Development		
			Low	Intermediate	High
JAN	374	$ 594	$ 594	$ 594	$ 594
FEB	351	461	461	461	461
MAR	357	228	228	228	228
APR	406	213	213	218	223
MAY	461	452	475	475	480
JUN	709	985	985	991	992
JUL	1,007	1,440	1,440	1,440	1,449
AUG	627	815	883	883	896
SEP	442	614	640	645	650
OCT	408	567	582	582	582
NOV	375	236	236	236	236
DEC	377	426	426	426	426
ANNUAL TOTAL	5,894	$7,031	$7,163	$7,179	$7,217

CONVERSION: 1,000,000 gal = 3,785,000 l

[a]Mean values, 1971-1975

TABLE 2. Electrical cost of Miles City municipal water supply system.

MONTH	WATER USED[a] (Million Gallons)	ELECTRICAL COST			
		Natural Flow	Levels of Development		
			Low	Intermediate	High
JAN	38	$ 507	$ 527	$ 528	$ 535
FEB	32	385	390	390	390
MAR	33	344	344	344	351
APR	34	358	361	370	370
MAY	48	527	527	530	533
JUN	88	907	912	912	916
JUL	88	956	961	963	967
AUG	69	718	862	896	985
SEP	57	612	695	713	770
OCT	45	481	489	489	500
NOV	41	456	461	465	466
DEC	33	429	440	440	445
ANNUAL TOTAL	606	$6,680	$6,969	$7,040	$7,228

CONVERSION: 1,000,000 gal = 3,785,000 l

[a]Mean values, 1974

GLENDIVE

The Glendive pumping plant (figure 5) has had no problems getting water during low flows in summer because the sump is imbedded in the river bottom. Ice jams usually do not occur in the river at the pumping plant site (Winchel 1976).

Shown in table 3 are the estimated monthly average costs for electricity to operate the Glendive municipal water supply system (Glendive 1976). The costs listed reflect streamflows in the Yellowstone River at Glendive for the natural flow and for the low, intermediate, and high levels of development. Streamflows for the three levels of development are presented in appendix D.

TABLE 3. Electrical cost of Glendive municipal water supply system.

MONTH	WATER USED[a] (Million Gallons)	ELECTRICAL COST			
		Natural Flow	Levels of Development Low	Intermediate	High
JAN	23	$ 51	$ 56	$ 57	$ 58
FEB	18	38	39	40	43
MAR	19	41	41	41	41
APR	23	49	50	50	50
MAY	25	54	54	54	54
JUN	60	128	128	128	128
JUL	84	179	180	180	180
AUG	55	119	119	119	119
SEP	29	63	63	64	66
OCT	25	54	54	54	54
NOV	18	39	39	39	39
DEC	18	41	43	44	45
ANNUAL TOTAL	397	$856	$866	$870	$877

CONVERSION: 1,000,000 gal = 3,785,000 l

[a]Mean values, July 1973-June 1975

The electrical cost data presented in table 3 project increases in annual operating costs for the Glendive system of 1 to 2.5 percent, depending on the level of development and corresponding impact on river flow.

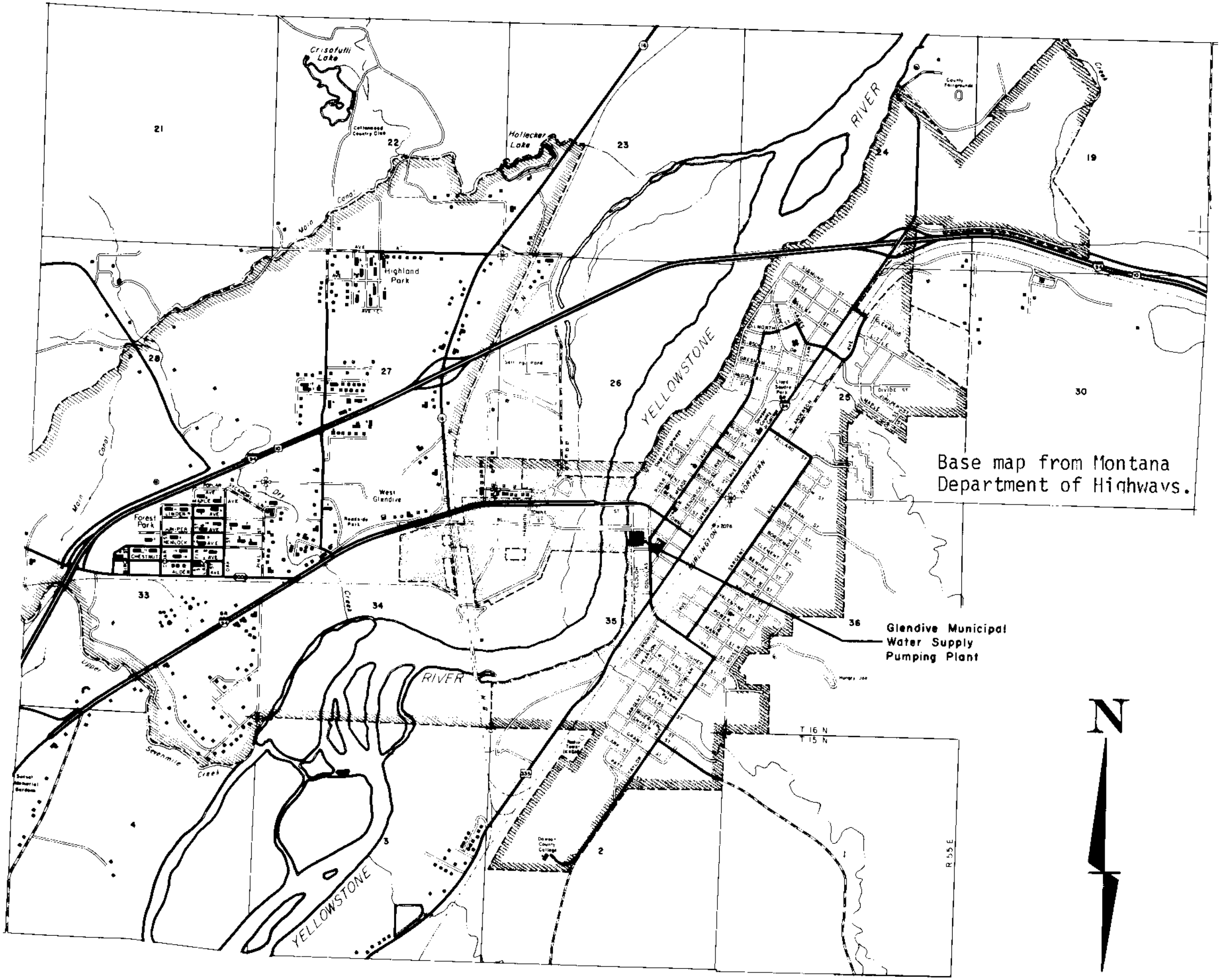


Figure 5. Glendive municipal water supply system.

IRRIGATION SYSTEMS

PUMPING DIVERSIONS

Kinsey No. 7

The Kinsey No. 7 pump station on the Yellowstone River is operated by the Kinsey Irrigation Company. The project provides water for 6,200 acres. The pumps at the river had a capacity of 150 cfs in 1948 (Montana State Engineer's Office 1948a).

Table 4 presents the irrigation pumping cost at Kinsey No. 7 for each of the projected levels of development at the 50th and 90th percentile flow values (see Report No. 1 in this series for a discussion of the percentile flows).

Table 5 shows the percentage increases in the pumping cost at Kinsey No. 7 for the low, intermediate, and high levels of development as compared to natural river flows.

TABLE 4. Irrigation pumping costs for Kinsey No. 7 (Yellowstone River) at present and future levels of development (dollars per acre-foot pumped).

	MONTH	NATURAL FLOW	LEVEL OF DEVELOPMENT		
			Low	Intermediate	High
50th Percentile Flows	May	.0305	.0312	.0318	.0322
	Jun	.0301	.0302	.0304	.0304
	Jul	.0419	.0433	.0435	.0443
	Aug	.0625	.0640	.0645	.0661
	Sep	.0405	.0430	.0432	.0450
90th Percentile Flows	May	.0378	.0396	.0403	.0418
	Jun	.0348	.0362	.0363	.0365
	Jul	.0500	.0522	.0530	.0547
	Aug	.0670	.0692	.0701	.0730
	Sep	.0570	.0580	.0590	.0610

CONVERSION: $1/af = $810/$hm^3$

Sidney No. 1, No. 2, and No. 3

Three pumping irrigation diversions at Sidney (Sidney No. 1, No. 2, and No. 3) are part of an irrigation project owned by the state of Montana. The Sidney Water Users Association operates the project, with assistance from the Montana Department of Natural Resources and Conservation. The Sidney pumping diversions have capacities as follows: 30 cfs (.85 m^3/s) for No. 1; 64 cfs (1.81 m^3/s) for No. 2; and 29 cfs (.85 m^3/s) for No. 3. The three diversion systems irrigate 1,240, 2,575, and 1,000 acres (306, 635 and 247 hectares) respectively (Montana DNRC 1973).

TABLE 5. Percentage increases in pumping cost at Kinsey No. 7 (Yellowstone River) for projected levels of development compared to natural flow.

	MONTH	LEVEL OF DEVELOPMENT		
		Low	Intermediate	High
50th Percentile Flows	May	2.3	4.3	5.6
	Jun	0.3	1.0	1.0
	Jul	3.3	3.8	5.7
	Aug	2.4	3.2	5.8
	Sep	6.2	6.7	11.1
90th Percentile Flows	May	4.8	6.6	10.6
	Jun	4.0	4.3	4.9
	Jul	4.4	6.0	9.4
	Aug	3.3	4.6	9.0
	Sep	1.8	3.5	7.0

Listed in table 6 are irrigation pumping costs for Sidney No. 1 for each of the projected levels of development. The figures are for the 50th and 90th percentile flow values (see Report No. 1 in this series).

TABLE 6. Irrigation pumping costs for Sidney No. 1 (Yellowstone River) for present and projected levels of development (dollars per acre-foot pumped).

	MONTH	NATURAL FLOW	LEVELS OF DEVELOPMENT		
			Low	Intermediate	High
50th Percentile Flows	May	.0941	.0950	.0954	.0958
	Jun	.0880	.0884	.0887	.0885[a]
	Jul	.0935	.0948	.0949	.0956
	Aug	.1019	.1035	.1040	.1055
	Sep	.1019	.1038	.1041	.1050
90th Percentile Flows	May	.1000	.1012	.1020	.1030
	Jun	.0934	.0940	.0942	.0948
	Jul	.1005	.1028	.1035	.1046
	Aug	.1060	.1085	.1093	.1110
	Sep	.1060	.1078	.1080	.1095

CONVERSION: $1/af = $810/hm^3

[a]Apparent anomaly due to change in pump efficiency at this development level.

Table 7 shows the percentage increases in pumping costs at Sidney No. 1 for the low, intermediate, and high levels of development as compared to the natural river flows.

TABLE 7. Percentage increases in pumping cost at Sidney No. 1 (Yellowstone River) for projected levels of development compared to natural flows.

	MONTH	LEVELS OF DEVELOPMENT		
		Low	Intermediate	High
50th Percentile Flows	May	1.0	1.4	1.8
	Jun	0.5	0.8	0.6
	Jul	1.4	1.5	2.3
	Aug	1.6	2.1	3.5
	Sep	1.9	2.2	3.0
90th Percentile Flows	May	1.2	2.0	3.0
	Jun	0.6	0.9	1.5
	Jul	2.3	3.0	4.1
	Aug	2.4	3.1	3.8
	Sep	1.7	1.9	3.3

Presented in table 8 are the irrigation pumping costs for Sidney No. 2 for each of the projected levels of development at the 50th percentile and 90th percentile flow values (see Report No. 1 in this series).

TABLE 8. Irrigation pumping costs at Sidney No. 2 (Yellowstone River) for present and projected levels of development (dollars per acre-foot pumped).

	MONTH	NATURAL FLOW	LEVELS OF DEVELOPMENT		
			Low	Intermediate	High
50th Percentile Flows	May	.1118	.1122	.1125	.1130
	Jun	.1158	.1060	.1063	.1061[a]
	Jul	.1110	.1120	.1122	.1128
	Aug	.1168	.1179	.1183	.1191
	Sep	.1168	.1181	.1184	.1190
90th Percentile Flows	May	.1158	.1165	.1170	.1175
	Jun	.1110	.1118	.1119	.1120
	Jul	.1160	.1172	.1180	.1185
	Aug	.1195	.1210	.1218	.1230
	Sep	.1198	.1203	.1205	.1218

CONVERSION: $1/af = $810/hm^3

[a]Apparent anomaly due to change in pump efficiency at this development level.

Table 9 shows the percentage increases in pumping cost at Sidney No. 2 for the low, intermediate, and high levels of development as compared to natural river flows.

TABLE 9. Percentage increases in pumping cost at Sidney No. 2 (Yellowstone River) for projected levels of development compared to natural flows.

	MONTH	LEVEL OF DEVELOPMENT		
		Low	Intermediate	High
50th Percentile Flows	May	0.4	0.6	1.1
	Jun	0.2	0.5	0.3[a]
	Jul	0.9	1.1	1.6
	Aug	0.9	1.3	2.0
	Sep	1.1	1.4	1.9
90th Percentile Flows	May	0.6	1.0	1.5
	Jun	0.7	0.8	0.9
	Jul	1.0	1.7	2.2
	Aug	1.3	1.9	2.9
	Sep	0.4	0.6	1.7

[a]Apparent anomaly due to change in pump efficiency at this development level.

Listed in table 10 are the irrigation pumping costs for the pumping diversion Sidney No. 3 for each of the projected levels of development.

TABLE 10. Irrigation pumping costs at Sidney No. 3 (Yellowstone River) for present and projected levels of development (dollars per acre-foot pumped).

	MONTH	NATURAL FLOW	LEVEL OF DEVELOPMENT		
			Low	Intermediate	High
50th Percentile Flows	May	.0749	.0760	.0765	.0770
	Jun	.0684	.0688	.0689	.0689
	Jul	.0739	.0755	.0760	.0770
	Aug	.0845	.0868	.0872	.0882
	Sep	.0845	.0868	.0872	.0882
90th Percentile Flows	May	.0824	.0839	.0852	.0855
	Jun	.0738	.0784	.0750	.0755
	Jul	.0829	.0855	.0862	.0875
	Aug	.0892	.0920	.0930	.0960
	Sep	.0895	.0908	.0910	.0930

CONVERSION: $1/af = $810/hm^3

Table 11 shows the percentage of increase in pumping cost at Sidney No. 3 for the low, intermediate, and high levels of development as compared to the natural flows.

TABLE 11. Percentage increases in pumping cost at Sidney No. 3 (Yellowstone River) for projected levels of development compared to natural flows.

	MONTH	LEVEL OF DEVELOPMENT		
		Low	Intermediate	High
50th Percentile Flows	May	1.5	2.1	2.8
	Jun	0.6	0.6	0.6
	Jul	2.2	2.8	4.2
	Aug	2.4	3.0	5.3
	Sep	2.7	3.2	4.4
90th Percentile Flows	May	1.8	3.4	3.8
	Jun	1.4	1.6	2.3
	Jul	3.1	4.0	5.6
	Aug	3.1	4.3	7.6
	Sep	1.5	1.7	3.9

GRAVITY DIVERSIONS

Gravity diversion systems are either *controlled* or *uncontrolled*. A controlled diversion system has a structure across the diverted stream which allows the irrigator to control the head of water being diverted. In contrast, an uncontrolled gravity diversion system has only a headgate to divert water into the system.

Controlled Diversions

The controlled-diversion systems studied here probably would be unaffected by the various levels of development that have been projected. Surveys were made of all headgates and diversion dams. In all cases, the crests of the diversion dams were at a higher elevation than the bottoms of the headgates. In essence, they can, if necessary, physically divert all water in the river to the headgates to retain the head now being used for the system, thereby incurring no increased costs. (It is assumed that the normal spring runoff would scour the sediments deposited during low flows.)

Forsyth No. 11. The gravity irrigation diversion, Forsyth No. 11, on the Yellowstone River at Forsyth diverts water for the Cartersville Irrigation District System. This project waters approximately 9,000 acres (2,220 hectares). The diversion has an approximate capacity of 750 cfs (21.2 m^3/s). (Montana State Engineer's Office 1948b).

T & Y No. 8. The irrigation diversion south of Miles City, T & Y No. 8, diverts water from the Tongue River to the approximately 9,000 acres (2,220 hectares) of the Tongue and Yellowstone River Irrigation District. Maximum capacity of the diversion works and canal is about 250 cfs (7.08 m^3/s) (Montana State Engineer's Office 1948a).

Intake No. 4. The Intake diversion, Intake No. 4, provides irrigation water for the Lower Yellowstone Irrigation Project. Total irrigable area for this project is about 56,000 acres (13,800 hectares). The maximum capacity of the diversion is about 1,200 cfs (33.9 m^3/s). (Montana State Engineer's Office 1970).

Uncontrolled Diversions

It was impracticable during this study to inspect and survey all of the uncontrolled diversions on the Yellowstone River. The nine ditch systems selected were representative of the many types of uncontrolled diversions. These ditch systems, which were studied on October 13, 1976, are near the communities of Livingston, Columbus, and Huntley (appendix B).

Livingston Ditch. The diversion for this irrigation ditch south of Livingston is on a side channel of the Yellowstone River (figure B-1 of appendix B). A 140-foot (42.7-meter) concrete diversion dam raises the water level in the channel to provide a higher head on the headgate. The relative elevation of the diversion crest is 89.2 ft (27.2 m); the elevation of the bottom of the headgate is 85.5 ft (26.1 m). Therefore, water in the side channel always can be diverted into the irrigation system. Problems with the system would arise if the major flow of the Yellowstone were to go to the opposite channel.

Vallis Ditch. When the Vallis ditch was studied it was dry; flow in the Yellowstone River was at a relative elevation of 91.2 ft (27.8 m) and the bottom of the headgate is at 91.6 ft (27.9 m). To divert 2 ft (.6 m) of water into the headgate, a river elevation of 93.6 ft (28.5 m), i.e., a minimum river flow of approximately 8,000 cfs (226 m^3/s), is necessary.

Side Ditch. When this ditch was studied the flow into the canal was only 0.3 ft (.1 m) deep. To divert 2 ft (.6 m) of water into the canal, a minimum river flow of approximately 6,100 cfs (172 m^3/s) is necessary.

Ditch Ditch. When the Ditch Ditch was studied it was not diverting water. However, a dike approximately 150 ft (46 m) long had been built across a side channel to raise the water level and divert it into the ditch. To divert 2 ft (.6 m) of water into the ditch, a minimum river flow of approximately 2,500 cfs (70.8 m^3/s) is necessary.

Heart K Ditch. When studied, this ditch had approximately 0.24 ft (.07 m) of head at the gate. To divert 2 ft (.6 m) of water into the ditch, a minimum river discharge of 6,000 cfs (170 m^3/s) is necessary. This ditch and the Lower Heart K Ditch are built on a side channel of the Yellowstone.

Lower Heart K Ditch. When studied, this ditch had 0.6 ft (.2 m) of head at the gate. To divert 2 ft (.6 m) of water into the ditch, a minimum river flow of 5,300 cfs (150 m^3/s) is necessary. A landowner in the area indicated that this particular side channel of the river dries up in the winter.

Middle Windsor Ditch. The Middle Windsor Ditch has a concrete diversion dam across a side channel of the Yellowstone River. Flashboards are used to raise the water level. To divert 2 ft (.6 m) of head in the ditch, a minimum river flow of 5,600 cfs (158 m^3/s) is necessary.

Columbus Ditch. There was 2 ft (.6 m) of water at the headgate of the Columbus Ditch when it was studied. An adequate flow in this ditch is 3 ft (.9 m). To divert that amount, the river must be flowing a minimum of 5,000 cfs (141 m^3/s). The Columbus Ditch (figure B-2 of appendix B) is built on the main channel of the river; some flow splits into a side channel away from the headgate.

Huntley Ditch. The Huntley Ditch diversion (figure B-3 of appendix B) has a concrete dam across the Yellowstone River at the head of an island. A dike has been built across a side channel to force the river over the concrete dam. Headgates at the diversion upstream from the dam are built well below the crest of the dam and, therefore, should have no problem in getting water if the flow of the river continues to be directed toward the dam.

The Availability of Water for Uncontrolled Diversions. Most of the uncontrolled, gravity-diversion systems inspected during this study have problems obtaining sufficient water during times of low streamflows in the Yellowstone River. Almost all of the headgates are on side channels of the river. In some cases, a side channel has been diked or a dam has been built to raise the water to headgate elevation. This tactic seems to work in the short run, but it probably encourages rechanneling of the river to the side opposite the diversion.

One water user near Livingston said that the flood in 1974 caused most of the diversion problems that Livingston-area irrigators have now. High streamflows caused many shifts in the river channel, he said.

Among possible solutions to these problems are: ensuring adequate instream flows in the river; channeling the river to direct the flow in each case toward the headgates; and installing permanent main-channel diversion dams where necessary to help direct river flow to side-channel headgates.

Summary and conclusions

The purpose of this study was to investigate some of the adverse effects that a decrease in the accessibility of water, as a result of reduced flows, would have on the existing municipal and agricultural water users in the Yellowstone River Basin.

Studied were three municipalities and numerous agricultural diversions.

Presumably, these existing users have valid water rights which will protect their water from the competition of future appropriators. But existing uses also could be adversely affected by a decrease in the accessibility of water. Future diversions extensive enough to decrease flows could lower the surface elevation of the water in the river channel. Some diversion structures might thereupon require expensive modification. A lower water-surface elevation at pump intakes also could affect pumping efficiency thus increasing the energy cost of pumping.

MUNICIPAL WATER SYSTEMS

Billings, Miles City, and Glendive draw their municipal water supplies directly from the Yellowstone River. Before being pumped into the treatment plant proper, water pumped by low-service pumps under 10 to 30 (3 to 10 m) of head enters presettlement basins.

Data collected at the three municipal sites consisted of kilowatt-hours used by the municipal plants, total water pumped from the river, chemical water-treatment costs and streamflow data. For each of the municipal systems, an attempt was made to correlate the river water surface elevations and the number of gallons of water pumped per kwh. Results were inconclusive.

For all hypothetical future levels of development of the river an altered streamflow led to an altered water-surface elevation which did not have a significant effect on pumping costs at present power rates. It appears that reduced water-surface elevations would have an insignificant impact on water-system costs at Glendive, Miles City and Billings.

An exception would be the possible one-time cost which might be incurred in the event that a reconstruction of the intake structure would be required at Glendive. According to municipal treatment plant personnel, during August, 1977 a 2 ft. (.6 m) reduction in the river water-surface elevation at Glendive would have rendered this treatment plant inoperative. Reconstruction may be necessary even if no future development occurs.

The cost of municipal water for Billings, Miles City, and Glendive will increase in the future, due primarily to increased water consumption resulting from population growth and to probable increases in electricity rates.

Table 12 shows the present rate of water use for each of the three cities. It also shows consumption for each of the projected levels of development. To derive the table, water use was calculated by multiplying population projections for each of the three cities (for a discussion of how the projections were derived, see Report No. 1 in this series) by an assumed individual water-use rate of 200 gal (750 l) per person per day.

TABLE 12. Present use and projected use of water to meet demands at Billings, Miles City, and Glendive (mgd).

City	Present Use	Level of Development		
		Low	Intermediate	High
Billings	12.7	19.0	19.1	19.7
Miles City	1.8	3.2	3.3	4.1
Glendive	1.3	1.7	1.7	1.7

CONVERSION: 1,000,000 gal = 3,785,000 l

Lower water-surface elevations, although probably not affecting pumping costs significantly, could have an effect on the availability of water in drought years.

The percentage increase in the total cost of providing water to the three cities is shown in table 13. The figures presented reflect both the increase in consumption and the increase in pumping costs.

TABLE 13. Percentage increases in water system operating operation cost for projected levels of development in Billings, Miles City and Glendive.

City	Level of Development		
	Low	Intermediate	High
Billings	53	53	60
Miles City	85	93	146
Glendive	32	33	33

IRRIGATION SYSTEMS

Four pumping and twelve gravity irrigation diversions were examined for the effect of reduced streamflow on each diversion.

IRRIGATION PUMPING

Because they are in a part of the Yellowstone River drainage where lowered streamflows would occur, four irrigation pumping diversions were selected: Kinsey No. 7, Sidney No. 1, Sidney No. 2, and Sidney No. 3. Information concerning the pumps, sump detail, water use, and power use for these sites was easily accessible.

Cross sections of the river were surveyed, and a computer program was used to calculate water-surface profile at each cross section.

While surveying the cross sections, the water-surface elevation at each cross section was recorded and the flow in the river was calculated for each water-surface elevation. These water-surface profiles and discharge data were then used to calibarte the river stage versus discharge relationships computed in the water-surface profile computer program.

A cost analysis was made for each irrigation-pumping diversion. These analyses were successful because power costs for the pumps had been recorded.

The efficiency of river-based irrigation-pumping plants is greatly reduced during extremely low flows. When flows in the river decrease, pumping costs increase. The range of increase in pumping cost for each of the pump sites studied is shown in table 14.

TABLE 14. Percentage increase in irrigation pumping cost under natural low-flow conditions at Sidney and Kinsey pumping stations.

PUMP SITE	PERCENTAGE INCREASE (Month)	
	Low	High
Kinsey No. 7	0.3 (June)	11.1 (September)
Sidney No. 1	0.5 (June)	4.1 (August)
Sidney No. 2	0.2 (June)	2.9 (August)
Sidney No. 3	0.6 (June)	7.6 (August)

GRAVITY DIVERSIONS

Three of the gravity diversions selected for study (Forsyth No. 11, Tongue and Yellowstone No. 8, and Intake No. 4) have dams that extend the entire width of the river. They are major gravity diversions in the Lower Yellowstone Basin. These controlled gravity-diversions have no problems obtaining water for their distribution systems even when flows in the river are low. These projects have headgates which are below the crest of the diversion dams. Therefore, all of the water in the river potentially is available for diversion.

Nine other gravity-irrigation diversions, (seven near Livingston, one near Columbus, and one near Huntley) were studied. All of the canals have minor headgate structures built at the head end. Discharges and elevations of the bottoms of the headgates were measured at each of the diversions. These uncontrolled gravity diversions will have problems obtaining water for their distribution systems unless adequate flows are maintained in the Yellowstone River. In some cases, diking has been used to increase the head of water into the canals. This practice, if used extensively along the river, would encourage rechannelization. Irrigators might have to resort to channelization and elaborate diversion structures, or extensive reconstruction of canals and headgates if streamflows fall below the historical norms for which the systems were designed.

Appendixes

Appendix A

PROJECTIONS OF FUTURE USE

FIGURES

TABLES

In order to adequately and uniformly assess the potential effects of water withdrawals on the many aspects of the present study, projections of specific levels of future withdrawals were necessary. The methodology by which these projections were done is explained in Report No. 1 in this series, in which also the three projected levels of development, low, intermediate, and high, are explained in more detail. Summarized below, these three future levels of development were formulated for energy, irrigation, and municipal water use for each of the nine subbasins identified in figure A-1.

ENERGY WATER USE

In 1975, over 22 million tons of coal (19 million metric tons) were mined in the state, up from 14 million (13 million metric) in 1974, 11 million (10 million metric) in 1973, and 1 million (.9 million metric) in 1969. By 1980, even if no new contracts are entered, Montana's annual coal production will exceed 40 million tons (36 million metric tons). Coal reserves, estimated at over 50 billion economically strippable tons (45 billion metric tons) (Montana Energy Advisory Council 1976), pose no serious constraint to the levels of development projected, which range from 186.7 (170.3 metric) to 462.8 (419.9 metric) million tons stripped in the basin annually by the year 2000.

Table A-1 shows the amount of coal mined, total conversion production, and associated consumption for six coal development activities expected to take place in the basin by the year 2000. Table A-2 shows water consumption by subbasin for those six activities. Only the Bighorn, Mid-Yellowstone, Tongue, Powder, and Lower Yellowstone subbasins would experience coal mining or associated development in these projections.

IRRIGATION WATER USE

Lands in the basin which are now either fully or partially irrigated total about 263,000 ha (650,000 acres) and consume annually about 1,850 hm^3 (1.5 mmaf) of water. Irrigated agriculture in the Yellowstone Basin has been increasing since 1971 (Montana DNRC 1975). Much of this expansion can be attributed to the introduction of sprinkler irrigation systems.

After evaluating Yellowstone Basin land suitability for irrigation, considering soils, economic viability, and water availability (only the Yellowstone River and its four main tributaries, Clarks Fork, Bighorn, Tongue, and Powder, were considered as water sources), this study concluded that 95,900 ha (237,000 acres) in the basin are financially feasible for irrigation. These acres are identified by county and subbasin in table A-3; table A-4 presents projections of water depletion.

Three levels of development were projected. The lowest includes one-third, the intermediate, two-thirds, and the highest, all of the feasibly irrigable acreage.

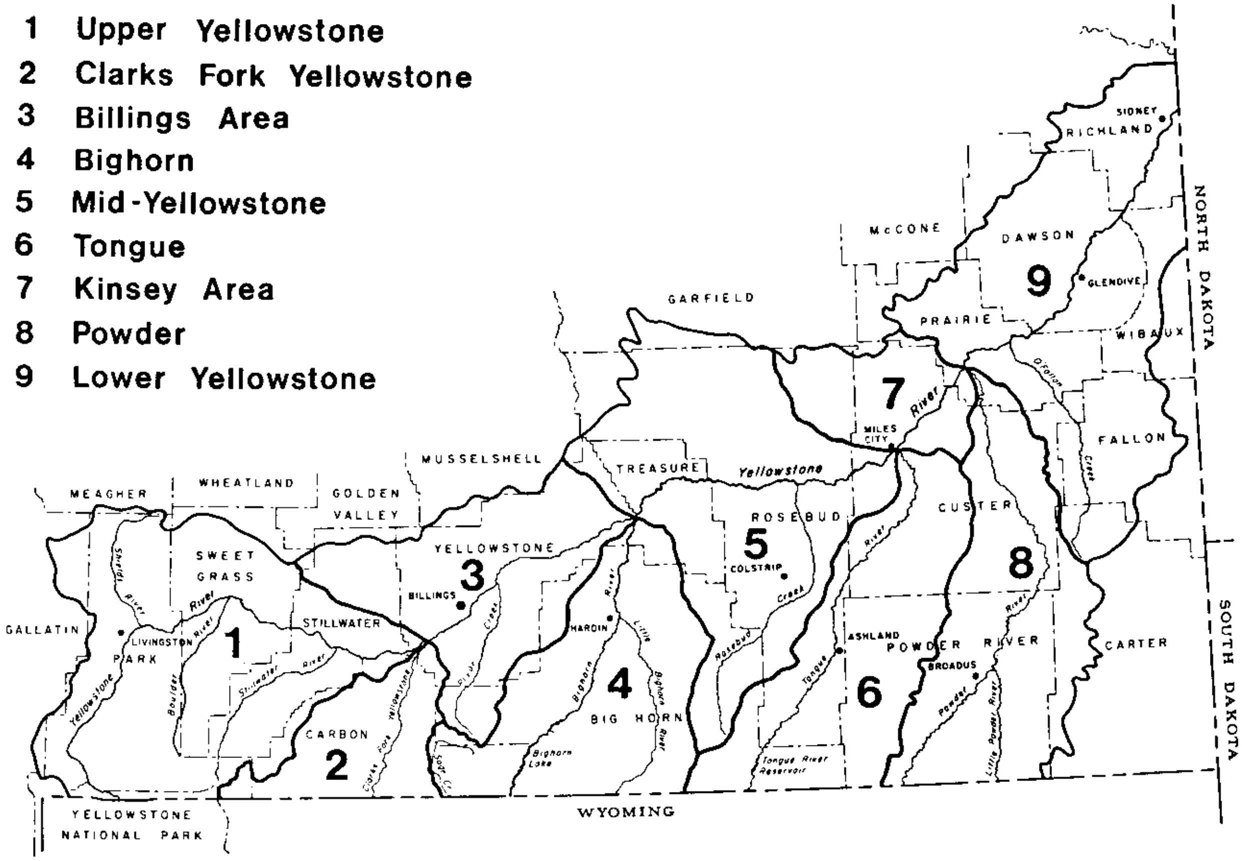


Figure A-1. The nine planning subbasins of the Yellowstone basin.

TABLE A-1. Increased water requirements for coal development in the Yellowstone Basin in 2000.

Level of Development	Coal Development Activity						Total
	Electric Generation	Gasification	Syncrude	Fertilizer	Export	Strip Mining	
			COAL MINED (mmt/y)				
Low	8.0	7.6	0.0	0.0	171.1		186.7
Intermediate	24.0	7.6	0.0	0.0	293.2		324.8
High	32.0	22.8	36.0	3.5	368.5		462.8
			CONVERSION PRODUCTION				
Low	2000 mw	250 mmcfd	0 b/d	0 t/d			
Intermediate	6000 mw	250 mmcfd	0 b/d	0 t/d			
High	8000 mw	750 mmcfd	200,000 b/d	2300 t/d			
			WATER CONSUMPTION (af/y)				
Low	30,000	9,000	0	0	[a]	9,350	48,350
Intermediate	90,000	9,000	0	0	31,910	16,250	147,160
High	120,000	27,000	58,000	13,000	80,210	22,980	321,190

CONVERSIONS: 1 mmt/y (short) = .907 mmt/y (metric)
1 af/y = .00123 hm^3/y

[a]No water consumption is shown for export under the low level of development because, for that development level, it is assumed that all export is by rail, rather than by slurry pipeline.

TABLE A-2. The increase in water depletion for energy by the year 2000 by subbasin.

Subbasin	INCREASE IN DEPLETION (af/y) Elec. Generation	Gasifi-cation	Syn-crude	Ferti-lizer	Export	Strip Mining	Total
			LOW LEVEL OF DEVELOPMENT				
Bighorn	0	0	0	0	0	860	860
Mid-Yellowstone	22,500	9,000	0	0	0	3,680	35,180
Tongue	7,500	0	0	0	0	3,950	11,450
Powder	0	0	0	0	0	860	860
Lower Yellowstone	0	0	0	0	0	0	0
Total	30,000	9,000				9,350	48,350
			INTERMEDIATE LEVEL OF DEVELOPMENT				
Bighorn	0	0	0	0	4,420	1,470	5,890
Mid-Yellowstone	45,000	9,000	0	0	15,380	6,110	75,490
Tongue	30,000	0	0	0	9,900	7,000	46,900
Powder	15,000	0	0	0	2,210	1,670	18,880
Lower Yellowstone	0	0	0	0	0	0	0
Total	90,000	9,000			31,910	16,250	147,160
			HIGH LEVEL OF DEVELOPMENT				
Bighorn	15,000	0	0	0	11,100	2,050	28,150
Mid-Yellowstone	45,000	18,000	29,000	0	38,700	8,710	139,410
Tongue	45,000	9,000	29,000	0	24,860	10,170	118,030
Powder	15,000	0	0	0	5,550	2,050	22,600
Lower Yellowstone	0	0	0	13,000	0	0	13,000
Total	120,000	27,000	58,000	13,000	80,210	22,980	321,190

CONVERSIONS: 1 af/y = .00123 hm^3/y

NOTE: The four subbasins not shown (Upper Yellowstone, Billings Area, Clarks Fork Yellowstone, Kinsey Area) are not expected to experience water depletion associated with coal development.

TABLE A-3. Feasibly irrigable acreage by county and subbasin by 2000, high level of development.

County	Upper Yellowstone	Clarks Fork	Billings Area	Big Horn	Mid Yellowstone	Tongue River	Kinsey Area	Powder River	Lower Yellowstone	County Totals
Park	21,664									21,664
Sweet Grass	10,204									10,204
Stillwater	6,208									6,208
Carbon		2,160								2,160
Yellow-stone			19,412							19,412
Big Horn				13,037		2,185				15,222
Treasure					9,591					9,591
Rosebud					11,408	9,727				21,135
Powder River								46,853		46,853
Custer					4,230	10,035	3,092	26,438		43,795
Prairie							1,644	1,914	8,231	11,789
Dawson									18,355	18,355
Richland									10,421	10,421
Wibaux									633	633
BASIN TOTALS	38,076	2,160	19,412	13,037	25,229	21,947	4,736	75,205	37,670	237,472

CONVERSIONS: 1 acre = .405 ha

NOTE: The number of irrigable acres for the low and intermediate development levels are one-third and two-thirds, respectively, of the numbers given here. This table should not be considered an exhaustive listing of all feasibly irrigable acreage in the Yellowstone Basin: it includes only the acreage identified as feasibly irrigable according to the geographic and economic constraints explained elsewhere in this report.

MUNICIPAL WATER USE

The basin's projected population increase and associated municipal water use depletion for each level of development are shown in table A-5. Even the 13 hm^3/y (10,620 af/y) depletion increase by 2000 shown for the highest development level is not significant compared to the projected depletion increases for irrigation or coal development. Nor is any problem anticipated in the availability of water to satisfy this increase in municipal use.

WATER AVAILABILITY FOR CONSUMPTIVE USE

The average annual yield of the Yellowstone River Basin at Sidney, Montana, at the 1970 level of development, is 10,850 hm^3 (8.8 million af). As shown in table A-6, the additional annual depletions required for the high projected level of development total about 999 hm^3 (812,000 acre-feet). Comparison of these two numbers might lead to the conclusion that there is ample water for such development, and more. That conclusion would be erroneous, however, because of the extreme variation of Yellowstone Basin streamflows from year to year, from month to month, and from place to place. At certain places and at certain times the water supply will be adequate in the foreseeable future. But in some of the tributaries and during low-flow times of many years, water availability problems, even under the low level of development, will be very real and sometimes very serious.

TABLE A-4. The increase in water depletion for irrigated agriculture by 2000 by subbasin.

Subbasin	Acreage Increase	Increase in Depletion (af/y)
HIGH LEVEL OF DEVELOPMENT		
Upper Yellowstone	38,080	76,160
Clarks Fork	2,160	4,320
Billings Area	19,410	38,820
Bighorn	13,040	26,080
Mid-Yellowstone	25,230	50,460
Tongue	21,950	43,900
Kinsey Area	4,740	9,480
Powder	75,200	150,400
Lower Yellowstone	37,670	75,340
TOTAL	237,480	474,960
INTERMEDIATE LEVEL OF DEVELOPMENT		
BASIN TOTAL	158,320	316,640
LOW LEVEL OF DEVELOPMENT		
BASIN TOTAL	79,160	158,320

CONVERSIONS: 1 acre = .405 ha
1 af/y = .00123 hm^3/y

NOTE: The numbers of irrigated acres at the low and intermediate levels of development are not shown by subbasin; however, those numbers are one-third and two-thirds, respectively, of the acres shown for each subbasin at the high level of development.

TABLE A-5. The increase in water depletion for municipal use by 2000.

Level of Development	Population Increase	Increase in Depletion (af/y)
Low	56,858	5,880
Intermediate	62,940	6,960
High	94,150	10,620

CONVERSIONS: 1 af/y = .00123 hm^3/y

TABLE A-6. The increase in water depletion for consumptive use by 2000 by subbasin.

Subbasin	Increase in Depletion (af/y) Irrigation	Energy	Municipal	Total
	LOW LEVEL OF DEVELOPMENT			
Upper Yellowstone	25,380	0	0	25,380
Clarks Fork	1,440	0	0	1,440
Billings Area	12,940	0	3,480	16,420
Bighorn	8,700	860	negligible	9,560
Mid-Yellowstone	16,820	35,180	1,680	53,680
Tongue	14,640	11,450	negligible	26,090
Kinsey Area	3,160	0	0	3,160
Powder	50,140	860	360	51,360
Lower Yellowstone	25,120	0	360	25,480
TOTAL	158,340	48,350	5,880	212,570
	INTERMEDIATE LEVEL OF DEVELOPMENT			
Upper Yellowstone	50,780	0	0	50,780
Clarks Fork	2,880	0	0	2,880
Billings Area	25,880	0	3,540	29,420
Bighorn	17,380	5,890	300	23,570
Mid-Yellowstone	33,640	75,490	1,860	110,990
Tongue	29,260	46,900	300	76,460
Kinsey Area	6,320	0	0	6,320
Powder	100,280	18,880	600	119,760
Lower Yellowstone	50,200	0	360	50,560
TOTAL	316,620	147,160	6,960	470,740
	HIGH LEVEL OF DEVELOPMENT			
Upper Yellowstone	76,160	0	0	76,160
Clarks Fork	4,320	0	0	4,320
Billings Area	38,820	0	3,900	42,720
Bighorn	26,080	28,150	480	54,710
Mid-Yellowstone	50,460	139,410	3,840	193,710
Tongue	43,900	118,030	780	162,710
Kinsey Area	9,480	0	0	9,480
Powder	150,400	22,600	1,140	174,140
Lower Yellowstone	75,340	13,000	480	88,820
TOTAL	474,960	321,190	10,620	806,770

CONVERSIONS: 1 af/y = .00123 hm^3/y

Appendix B

DETAILED MAPS OF IRRIGATION SYSTEMS STUDIED

FIGURES

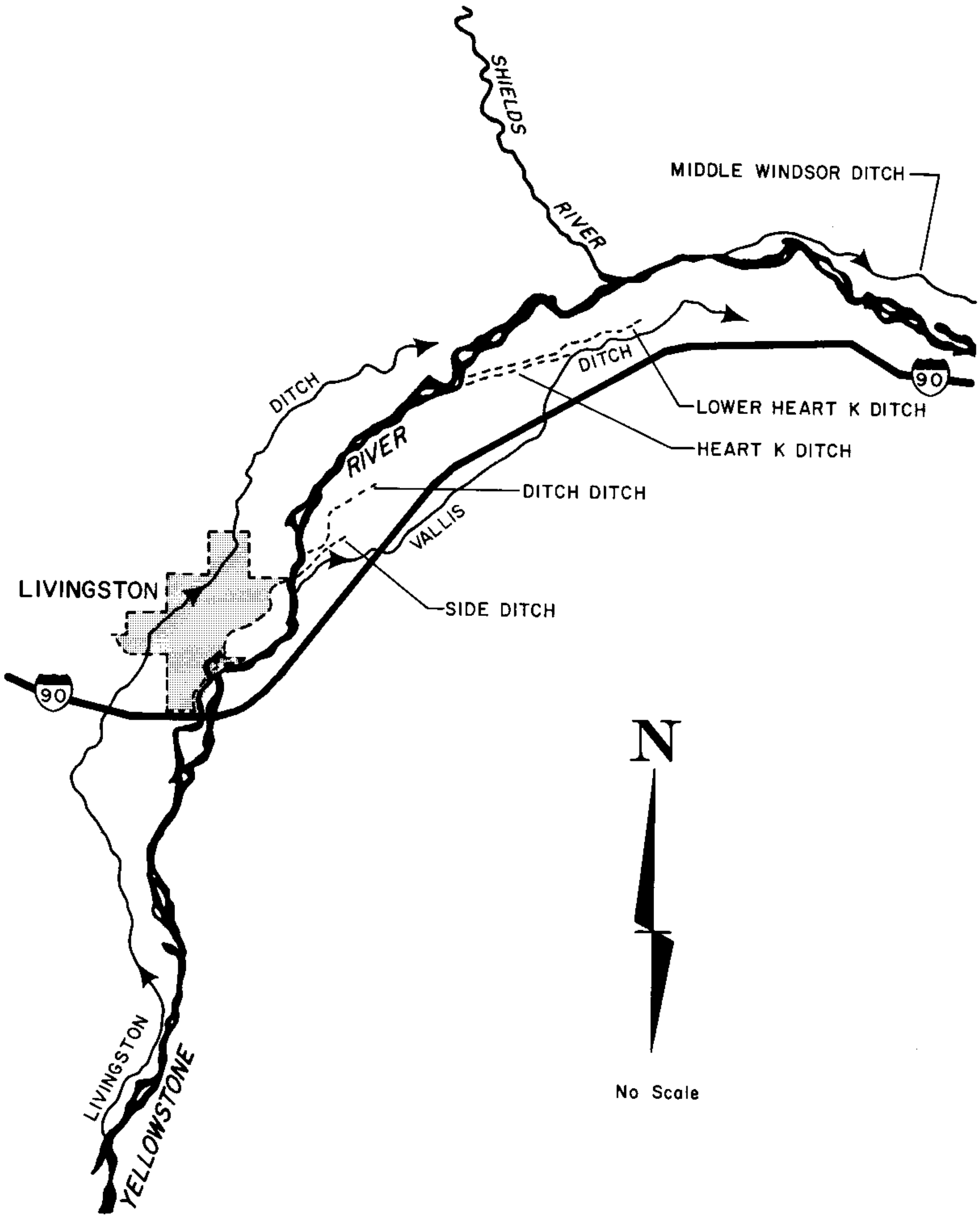


Figure B-1. Location of irrigation diversions near Livingston.

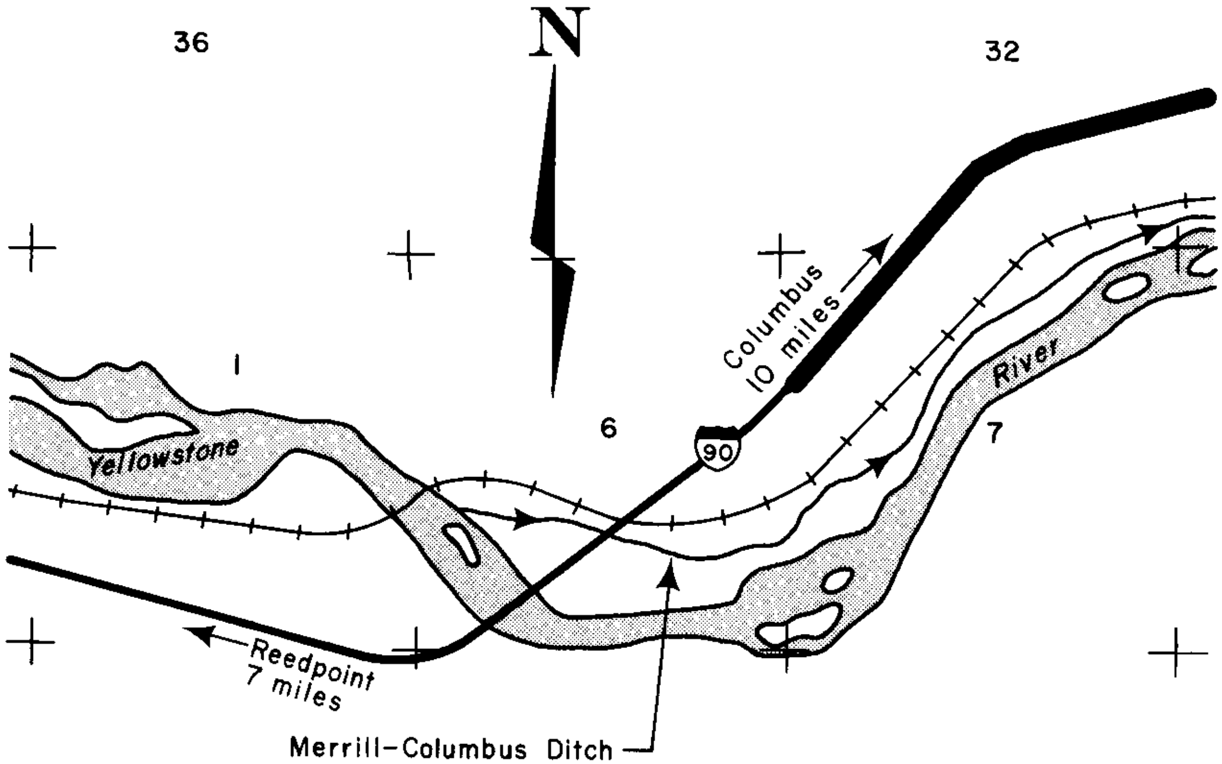


Figure B-2. Location of irrigation diversion near Columbus.

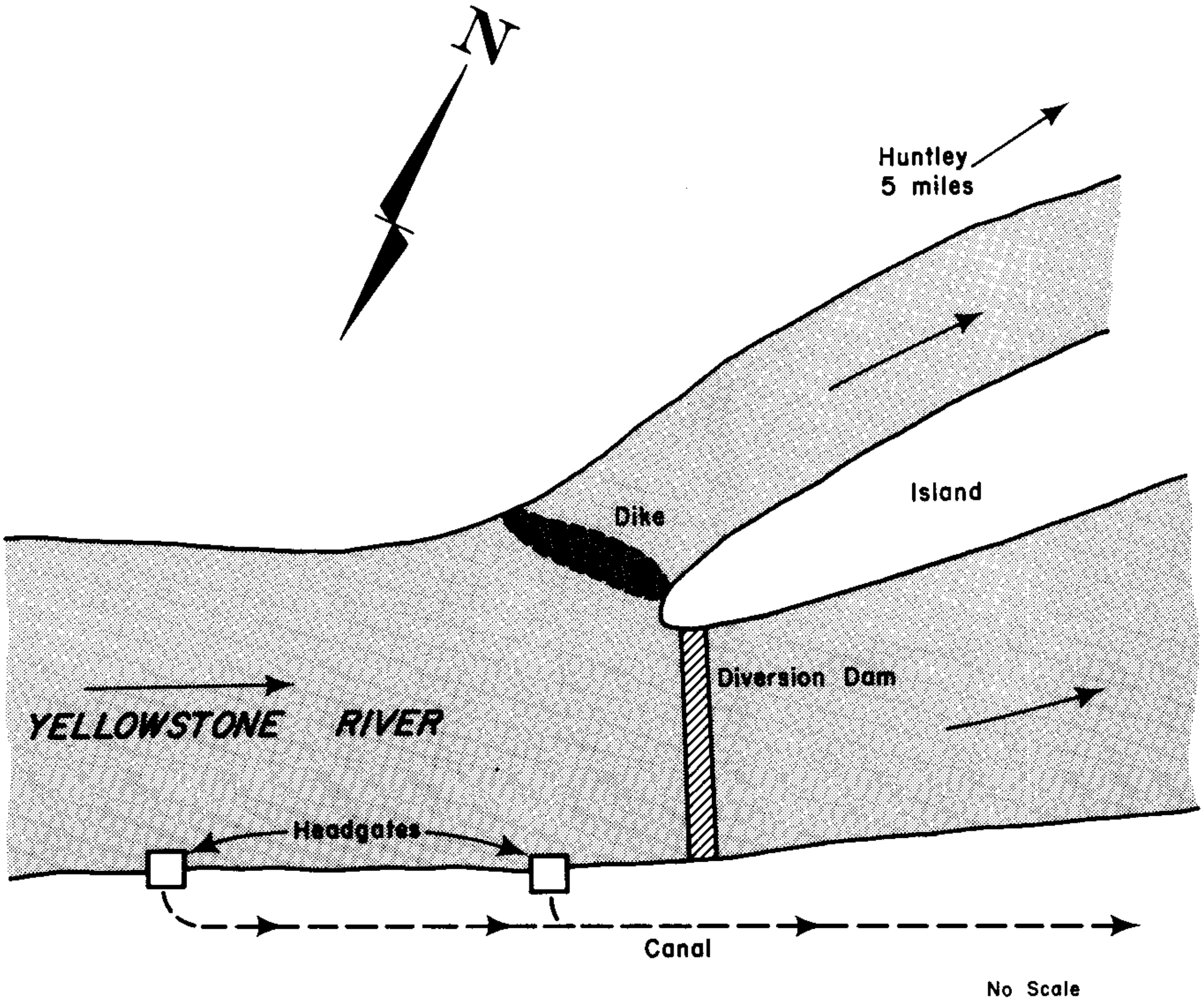


Figure B-3. Location of irrigation diversion near Huntley.

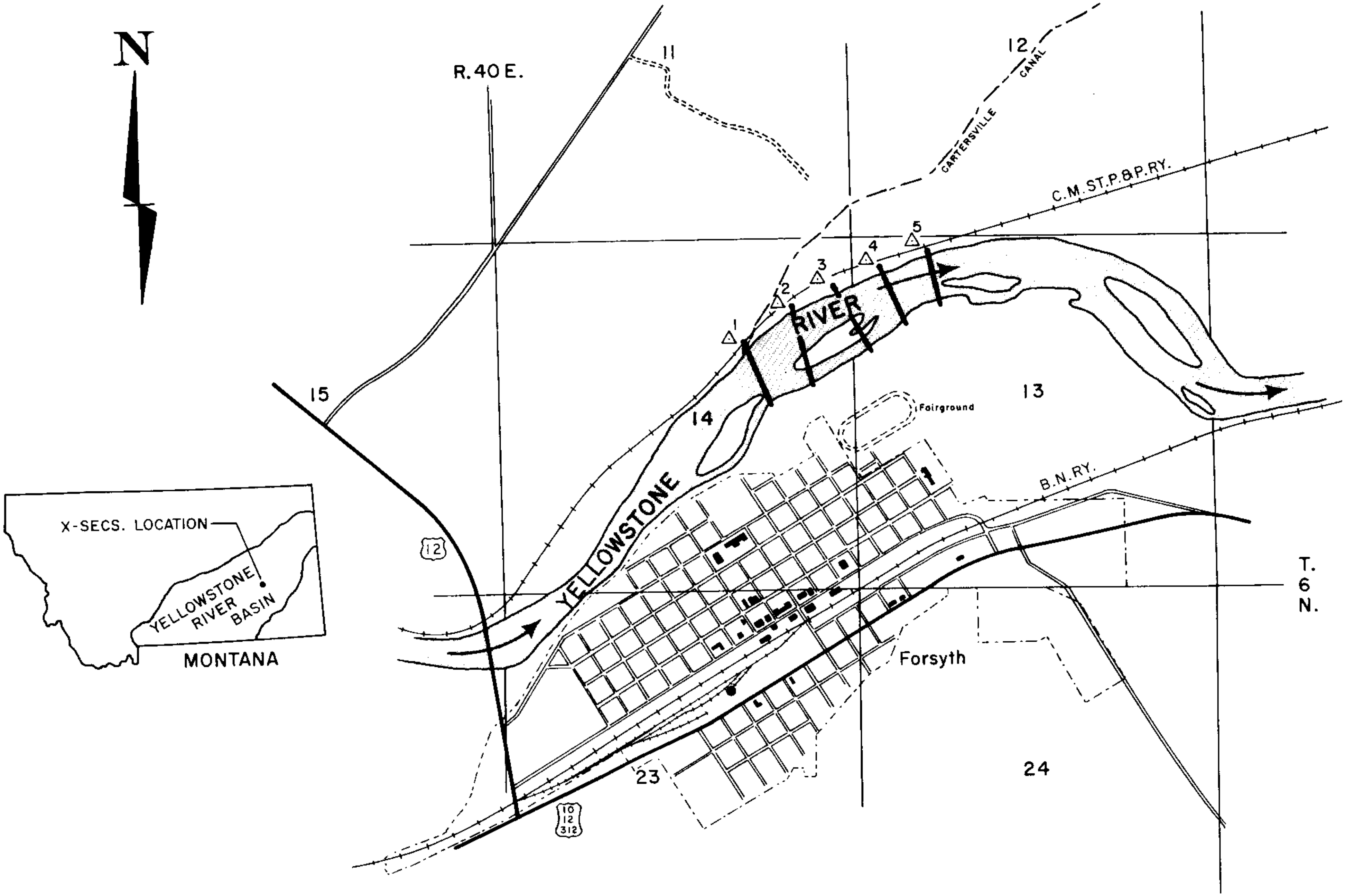


Figure B-4. Site location map and cross section locations, Forsyth Diversion Dam Project No. 11.

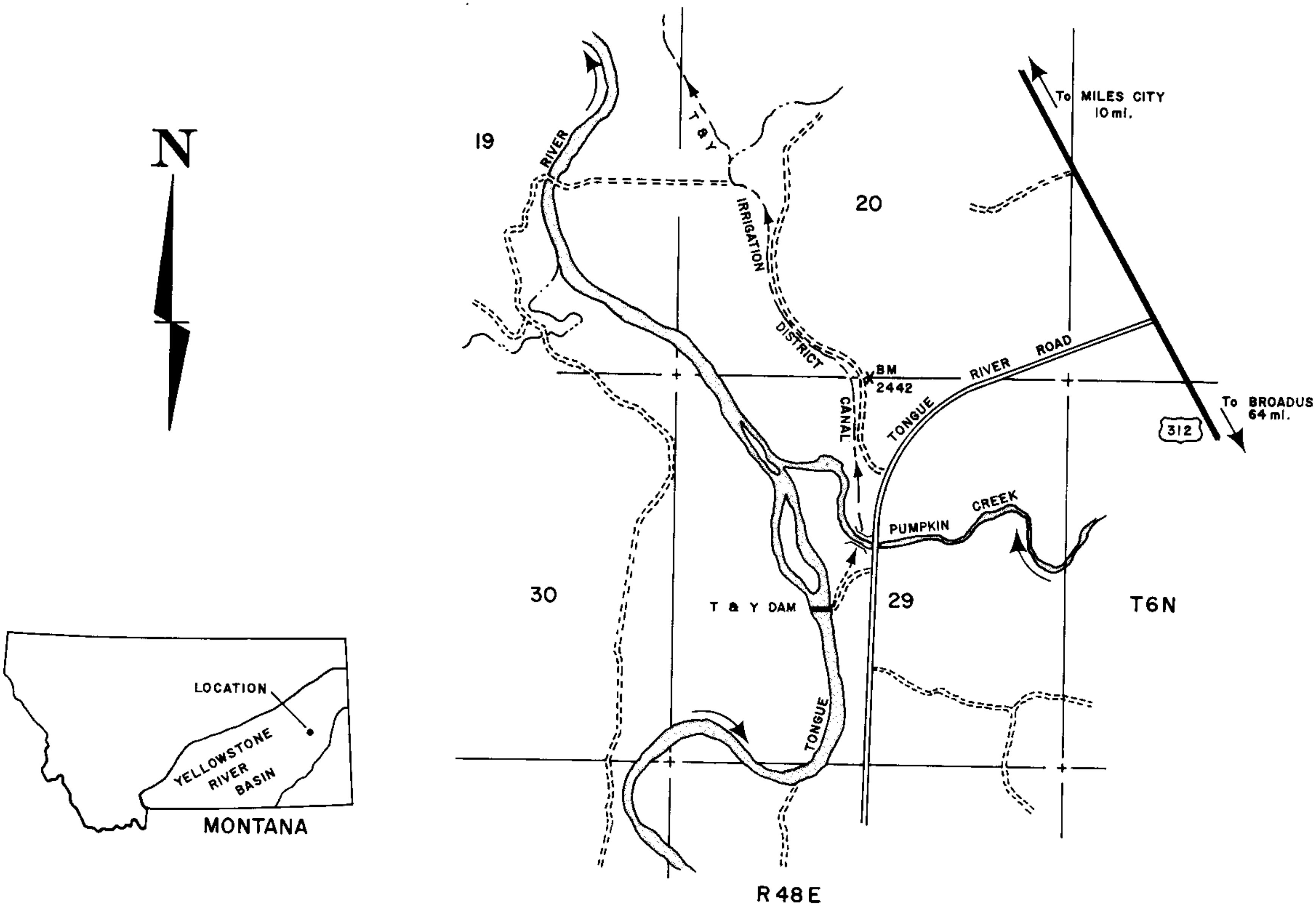


Figure B-5. Site location map, T & Y Diversion Dam Project No. 8.

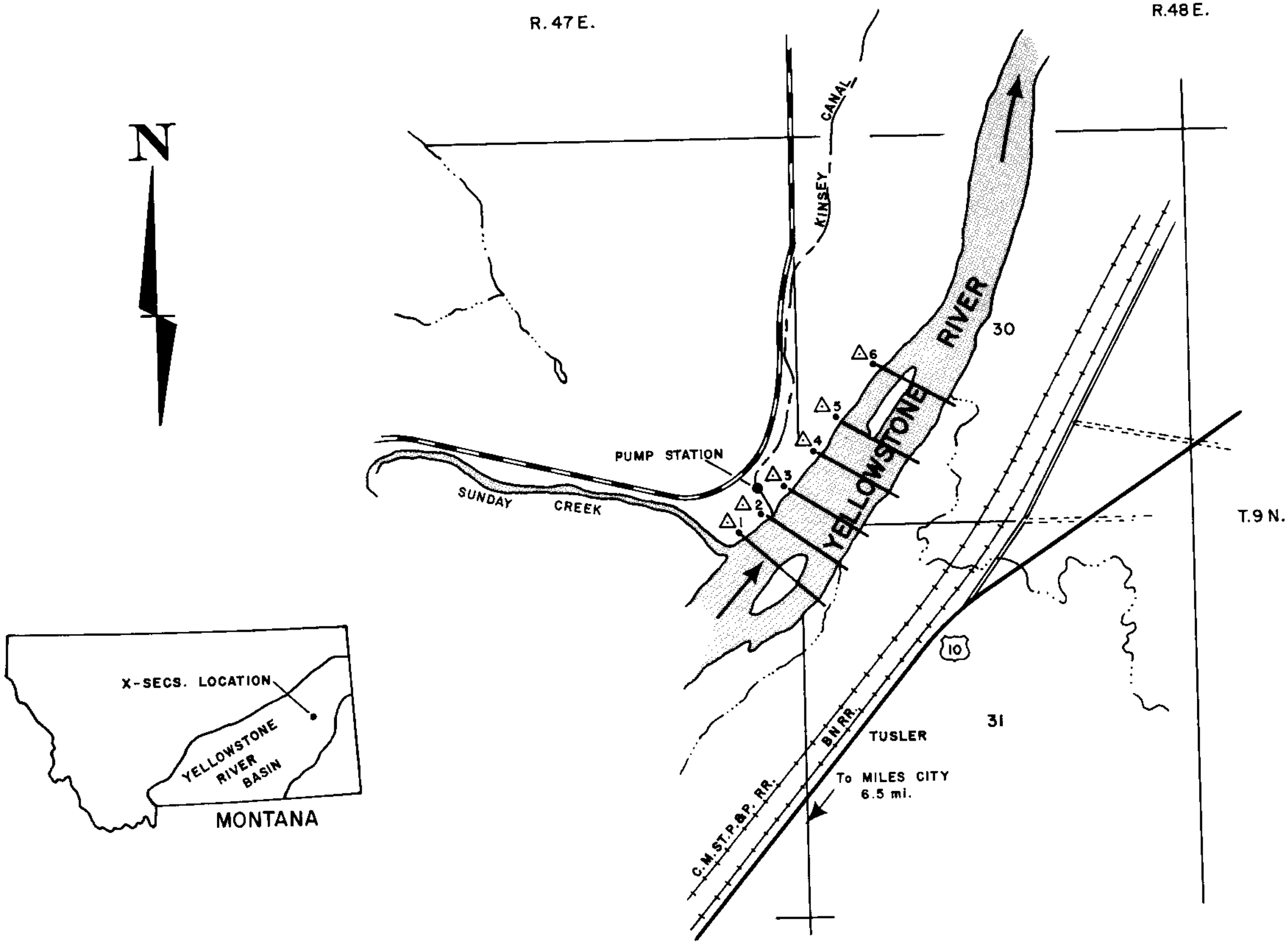


Figure B-6. Site location map and cross section locations, Kinsey Pumping Project No. 7.

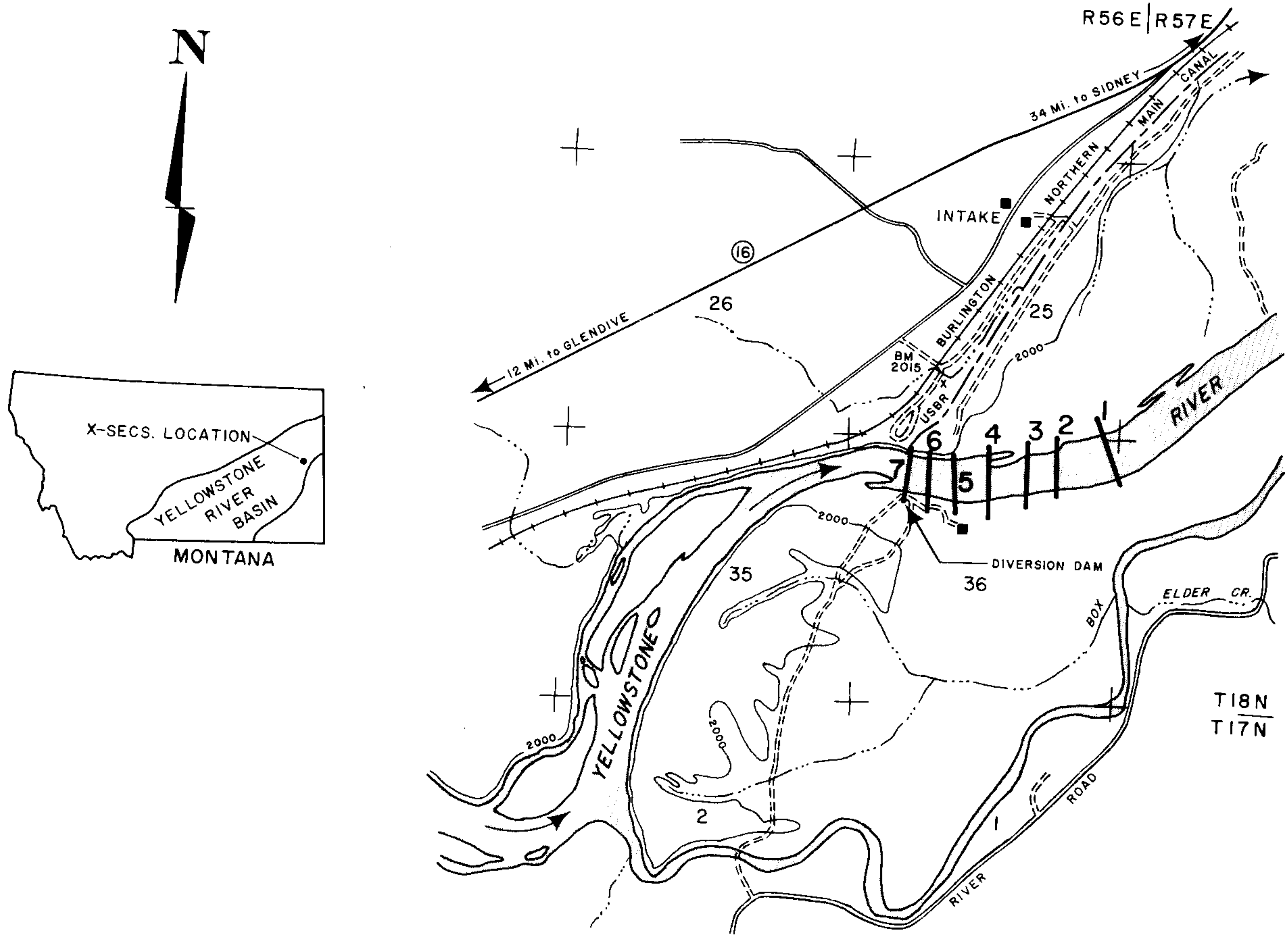


Figure B-7. Site location map and cross section locations, Intake Diversion Dam Project No. 4.

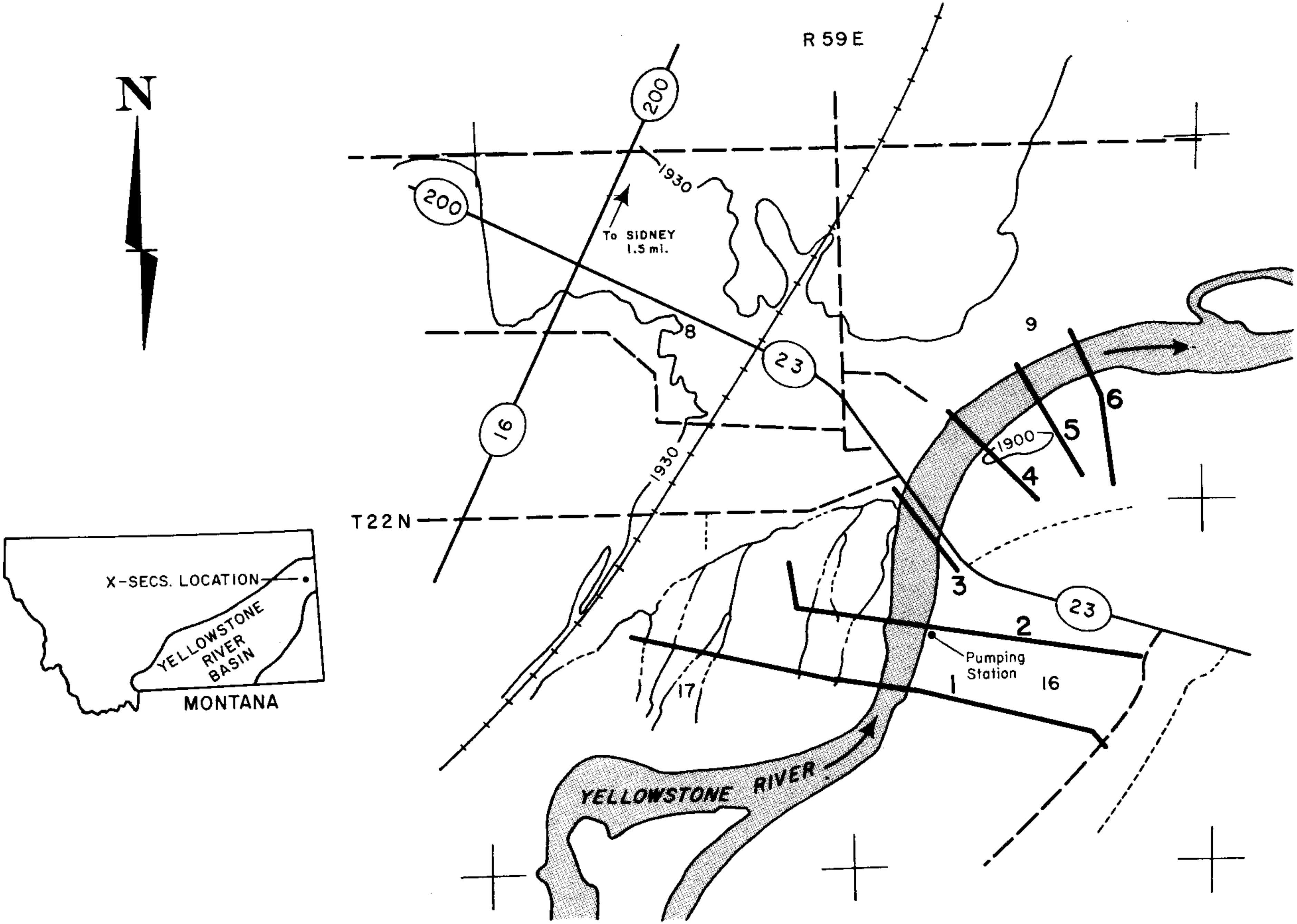


Figure B-8. Site location map and cross section locations, Sidney Pumping Project No. 3.

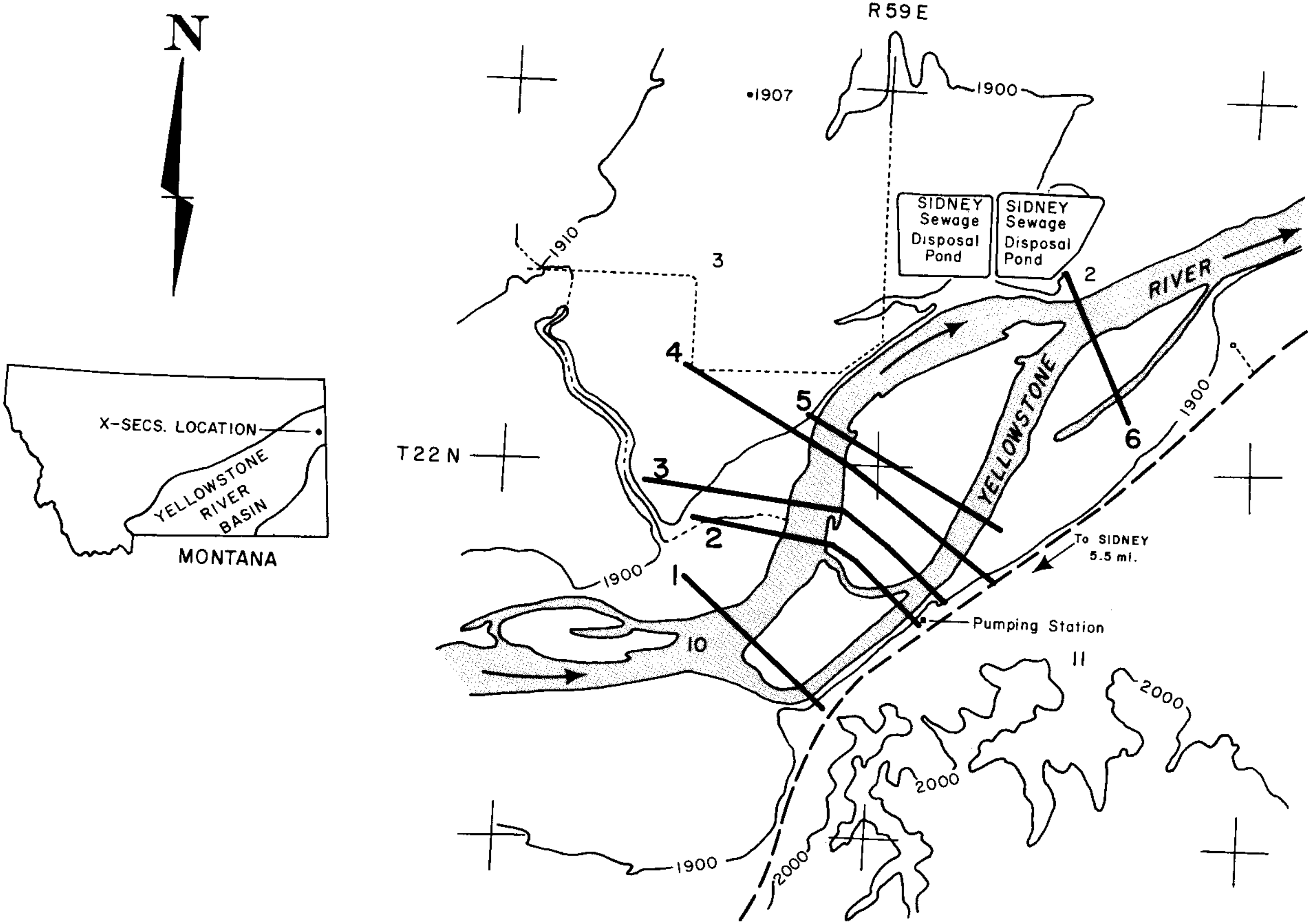


Figure B-9. Site location map and cross section locations, Sidney Pumping Project No. 2.

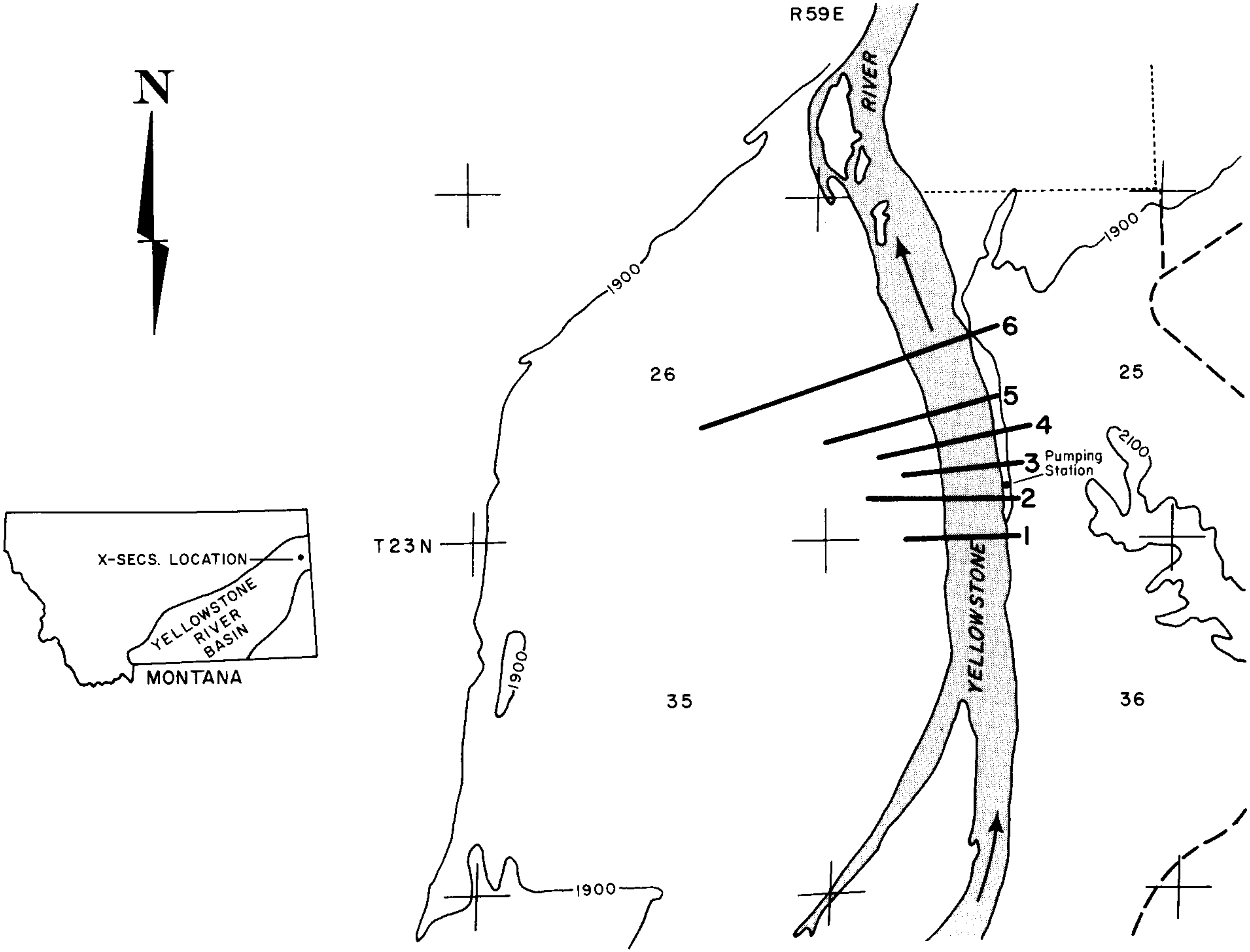


Figure B-10. Site location map and cross section locations, Sidney Pumping Project No. 1.

Appendix C

DISCHARGES IN THE YELLOWSTONE RIVER AT SIDNEY AND NEAR KINSEY FOR VARIOUS LEVELS OF DEVELOPMENT

TABLE C-1. Flow of the Yellowstone River near Kinsey for various levels of development (cfs).

	MONTH	NATURAL DISCHARGE	LEVEL OF DEVELOPMENT		
			Low	Intermediate	High
50th Percentile Flows	May	17,577	16,091	15,890	15,236
	Jun	37,566	35,789	35,532	34,704
	Jul	20,207	17,591	17,153	15,767
	Aug	7,460	4,982	4,636	3,515
	Sep	7,196	5,749	5,565	4,894
90th Percentile Flows	May	8,520	7,153	6,951	6,299
	Jun	21,526	19,760	19,503	18,676
	Jul	8,917	6,658	6,220	5,298
	Aug	4,479	2,328	1,984	1,055
	Sep	4,251	3,543	3,359	2,313

CONVERSION: 1 cfs = .02832 m^3/s

TABLE C-2. Flow of the Yellowstone River at Sidney for various levels of development (cfs).

	MONTH	NATURAL DISCHARGE	LEVEL OF DEVELOPMENT		
			Low	Intermediate	High
50th Percentile Flows	May	18,560	16,900	16,312	15,532
	Jun	39,013	37,300	36,225	36,700
	Jul	20,266	17,700	17,091	15,660
	Aug	7,270	5,760	5,267	4,094
	Sep	7,250	5,480	5,196	4,477
90th Percentile Flows	May	9,274	7,830	7,168	6,319
	Jun	20,460	18,880	18,505	17,663
	Jul	8,673	6,400	5,833	4,835
	Aug	3,873	2,250	1,785	792
	Sep	3,665	2,900	2,689	1,656

CONVERSION: 1 cfs = .02832 m^3/s

Appendix D

POWER-USE, WATER-USE, AND STREAMFLOW DATA FOR BILLINGS, MILES CITY, AND GLENDIVE MUNICIPAL WATER SUPPLY PLANTS AND LEVEL-OF-DEVELOPMENT STREAMFLOW DATA

TABLES

TABLE D-1. Power used, gallons pumped, gallons pumped per kilowatt-hour and corresponding river flow data, for the Billings municipal water supply plant (Monthly data).

Month/Year	Total kwh (x 10^3)	Water Pumped gal (x 10^6)	Gallons per kwh (x 10^3)	Flow in River (x 10^3 af/mo)
1-71	49.1	361	7.35	189.2
2-71	41.3	311	7.53	226.4
3-71	47.5	334	7.03	195.3
4-71	40.5	352	8.69	284.3
5-71	64.5	560	8.68	905.5
6-71	102.8	716	6.96	2,224.0
7-71	142.0	970	6.83	1,312.0
8-71	149.2	987	6.62	468.7
9-71	54.7	428	7.82	397.4
10-71	53.8	362	6.73	349.6
11-71	44.3	339	7.65	269.5
12-71	51.7	392	7.58	200.9
3-72	46.9	353	7.53	300.8
4-72	41.0	437	10.66	235.3
5-72	47.7	474	9.94	723.7
6-72	109.3	793	7.26	1,964.0
7-72	106.1	800	7.55	884.0
8-72	99.9	809	8.10	486.3
9-72	55.4	527	9.51	398.3
10-72	51.5	372	7.22	391.3
11-72	45.6	342	7.50	284.9
12-72	39.0	360	9.23	200.8
1-73	42.8	372	8.69	192.2
2-73	21.6	354	16.39	171.1
3-73	25.7	359	13.97	201.3
4-73	32.7	377	11.53	291.1
5-73	57.7	533	9.24	862.3
6-73	116.8	792	6.78	1,261.0
7-73	133.7	946	7.08	652.0
8-73	104.2	799	7.67	255.4
9-73	46.3	397	8.57	326.9
10-73	45.7	385	8.42	265.5
11-73	22.3	361	16.19	243.5
12-73	19.3	362	18.76	199.5
1-74	24.3	374	15.39	190.9
2-74	27.0	351	12.98	147.2
3-74	49.8	357	7.17	178.4
4-74	56.1	406	7.24	276.0
5-74	33.1	461	13.92	619.6
6-74	99.5	709	7.13	2,441.0
7-74	154.3	1,007	6.52	1,323.0
8-74	74.6	627	8.40	495.9

TABLE D-1. Continued

Month/Year	Total kwh (x 10^3)	Water Pumped gal (x 10^6)	Gallons per kwh (x 10^3)	Flow in River (x 10^3 af/mo)
9-74	53.3	442	8.29	301.8
10-74	54.4	408	7.49	257.7
11-74	53.7	375	6.98	245.6
12-74	53.4	377	7.06	181.9
1-75	59.2	372	6.28	150.3
2-75	35.2	330	9.38	123.5
3-75	55.0	353	6.43	213.8
4-75	48.0	346	7.22	307.2
5-75	47.5	396	8.34	913.6
6-75	71.0	537	7.57	1,957.0
7-75	122.0	923	7.57	2,286.0
8-75	101.9	814	7.99	556.1
9-75	70.5	599	8.50	296.9
10-75	65.1	415	6.37	
11-75	66.7	347	5.20	

CONVERSIONS: 1 gal = 3.785 l
1 af = .001233 hm^3

TABLE D-2. Level-of-development streamflow data, Yellowstone River at Billings.

		MEAN VALUES (10^3 af)		
	NATURAL FLOW	LOW	INTERMEDIATE	HIGH
JAN	154	154	154	154
FEB	168	168	168	168
MAR	223	222	223	223
APR	254	249	249	249
MAY	746	389	682	675
JUN	1,637	1,565	1,556	1,547
JUL	932	830	813	796
AUG	344	253	239	226
SEP	263	200	194	188
OCT	263	248	248	248
NOV	227	227	228	228
DEC	173	173	173	173

CONVERSION: 1 af = .001233 hm^3

TABLE D-3. Power used, gallons pumped, gallons pumped per kilowatt-hour, and corresponding river-flow data, for the Miles City municipal water supply plant.

mo/da/yr	Total kwh ($x 10^3$)	Water Pumped gal ($x 10^6$)	Gallons per kwh ($x 10^3$)	Flow in River ($x 10^3$ af/mo)
12/28/74	1.39	1.17	.84	10.7
12/18/74	1.29	1.03	.80	14.8
12/08/74	1.28	1.01	.79	16.2
11/28/74	1.42	1.26	.89	15.6
11/18/74	1.63	1.45	.89	18.4
11/07/74	1.39	1.37	.99	19.5
10/28/74	1.58	1.43	.91	17.7
10/18/74	1.43	1.51	1.06	18.4
10/08/74	1.45	1.37	.94	16.9
9/28/74	1.61	1.47	.91	15.3
9/18/74	2.27	2.40	1.06	17.2
9/08/74	2.06	1.83	.89	17.1
8/28/74	1.94	2.01	1.04	21.1
8/18/74	2.60	2.51	.97	20.8
8/08/74	1.65	2.19	1.33	20.9
7/28/74	3.19	2.95	.92	32.8
7/18/74	3.38	3.92	1.16	49.5
7/08/74	2.02	1.62	.80	80.6
6/28/74	3.19	4.24	1.33	118.0
6/18/74	3.19	3.47	1.09	114.7
6/08/74	1.24	1.10	.89	83.0
5/28/74	1.39	1.22	.88	31.6
5/18/74	1.80	1.23	.68	22.1
5/08/74	2.00	2.20	1.10	23.9
4/28/74	1.07	0.97	.91	29.4
4/18/74	1.17	1.25	1.07	20.9
4/08/74	1.04	1.15	1.11	18.1
3/28/74	.87	1.01	1.16	16.4
3/18/74	.93	.98	1.05	15.6
3/08/74	1.04	1.19	1.14	15.5
2/28/74	1.13	1.23	1.09	14.6
2/18/74	.96	.99	1.03	17.1
2/08/74	1.09	1.25	1.15	13.3
1/28/74	1.24	1.40	1.13	13.9
1/18/74	1.05	1.11	1.06	24.0
1/08/74	1.04	1.15	1.11	6.7

CONVERSIONS: 1 gal = 3.785 l
1 af = .001233 hm^3

TABLE D-4. Level-of-development streamflow data, Yellowstone River at Miles City.

	NATURAL FLOW	MEAN VALUES (10^3 af)		
		LOW	INTERMEDIATE	HIGH
JAN	318	300	300	288
FEB	348	345	342	332
MAR	493	493	490	481
APR	466	457	453	442
MAY	1,014	941	929	889
JUN	2,164	2,103	2,088	2,039
JUL	1,327	1,167	1,140	1,060
AUG	501	360	339	272
SEP	443	363	352	311
OCT	479	460	457	447
NOV	423	418	415	407
DEC	341	323	321	312

CONVERSION: 1 af = .001233 hm^3

TABLE D-5. Power used, gallons pumped, gallons pumped per kilowatt-hour, and corresponding river flow data, for the Glendive municipal water supply plant. (Monthly Data).

Month/Year	Total kwh ($x\ 10^3$)	Water Pumped gal ($x\ 10^6$)	Gallons per kwh ($x\ 10^3$)	Flow in River ($x\ 10^3$ af/mo)
7-73	15.1	88	5.8	934.5
8-73	13.8	86	6.2	479.0
9-73	4.6	22	4.8	787.3
10-73	4.5	22	4.9	669.7
11-73	3.6	17	4.7	620.0
12-73	3.8	19	5.0	445.3
1-74	4.2	23	5.5	411.8
2-74	3.6	18	5.0	446.3
3-74	3.8	19	5.0	557.0
4-74	4.6	23	5.0	708.9
5-74	5.1	25	4.9	1,018.9
6-74	13.0	60	4.6	3,027.3
7-74	17.6	84	4.7	2,052.3
8-74	12.6	55	4.4	739.7
9-74	9.6	29	3.0	570.6
10-74	5.7	25	4.4	582.3
11-74	4.0	18	4.5	596.7
12-74	3.8	18	4.7	482.4

TABLE D-5. Continued

Month/Year	Total kwh ($\times 10^3$)	Water Pumped gal ($\times 10^6$)	Gallons per kwh ($\times 10^3$)	Flow in River ($\times 10^3$ af/mo)
1-75	4.2	19	4.5	460.4
2-75	4.4	19	4.3	332.2
3-75	4.2	19	4.5	751.0
4-75	4.1	18	4.4	762.7
5-75	4.8	22	4.6	1,793.0
6-75	6.4	31	4.8	2,743.9

CONVERSIONS: 1 gal = 3.785 l
1 af = .001233 hm^3

TABLE D-6. Level-of-development streamflow data, Yellowstone River at Glendive.

	NATURAL FLOW	MEAN VALUES (10^3 af)		
		LOW	INTERMEDIATE	HIGH
JAN	343	322	315	299
FEB	396	378	364	347
MAR	707	652	624	608
APR	618	588	564	547
MAY	1,051	989	943	894
JUN	2,371	2,304	2,249	2,186
JUL	1,420	1,232	1,179	1,091
AUG	484	385	354	285
SEP	426	345	327	282
OCT	504	466	459	446
NOV	452	439	430	417
DEC	354	339	331	317

CONVERSION: 1 af = .001233 hm^3

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